(54) Title: SURGICAL ROBOTIC TOOLS, DATA ARCHITECTURE, AND USE

(57) Abstract

Robotic surgical tools, systems, and methods for preparing for, and performing robotic surgery include a memory (126) mounted on the tool (54). The memory (126) can perform a number of functions when the tool (54) is loaded on the tool manipulator (58). First, the memory can provide a signal verifying that the tool (54) is compatible with that particular robotic system. Secondly, the tool memory (126) may identify the tool-type to the robotic system so that the robotic system can reconfigure its programming. Thirdly, the memory (126) of the tool (54) may indicate tool specific information, including measured calibration offsets indicating misalignment of the tool drive system, tool life data, or the like. This information may be stored in a read only memory (ROM), or in a nonvolatile memory which can be written to only a single time. The invention further provides improved engagement structures for coupling robotic surgical tools with manipulator structures.

SURGICAL ROBOTIC TOOLS, DATA ARCHITECTURE, AND USE

CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims priority to U.S. Provisional Patent Appl. No. 60/111,713 filed on December 8, 1998, (Attorney Docket No. 17516-003200) the entirety of which is herein incorporated by reference.

BACKGROUND OF THE INVENTION

This invention relates to robotically assisted surgery, and more particularly provides surgical tools having improved mechanical and/or data interface capabilities to enhance the safety, accuracy, and speed of minimally invasive and other robotically enhanced surgical procedures.

In robotically assisted surgery, the surgeon typically operates a master controller to remotely control the motion of surgical instruments at the surgical site. The controller may be separated from the patient by a significant distance (e.g., across the operating room, in a different room, or in a completely different building than the patient). Alternatively, a controller may be positioned quite near the patient in the operating room. Regardless, the controller will typically include one or more hand input devices (such as joysticks, exoskeletol gloves, master manipulators, or the like) which are coupled by a servo mechanism to the surgical instrument. More specifically, servo motors move a manipulator or "slave" supporting the surgical instrument based on the surgeon's manipulation of the hand input devices. During an operation, the surgeon may employ, via the robotic surgery system, a variety of surgical instruments such as tissue graspers, needle drivers, electrosurgical cautery probes, etc. Each of these structures performs functions for the surgeon, for example, holding or driving a needle, grasping a blood vessel, or dissecting, cauterizing, or coagulating tissue.

This new method of performing robotic surgery has, of course, created many new challenges. One such challenge is that a surgeon will typically employ a significant number of different surgical instruments during each surgical procedure. The number of independent surgical manipulators will often be limited due to space constraints and cost. Additionally, patient trauma can generally be reduced by eliminating the number of tools used at any given time. More specifically, in minimally

invasive procedures, the number of entry ports into a patient is generally limited because of space constraints, as well as a desire to avoid unnecessary incisions in the patient. Hence, a number of different surgical instruments will typically be introduced through the same trocar sleeve into the abdomen during, for example, laparoscopic procedures.

5   Likewise, in open surgery, there is typically not enough room adjacent the surgical site to position more than a few surgical manipulators, particularly where each manipulator/tool combination has a relatively large range of motion. As a result, a number of surgical instruments will often be attached and detached from a single instrument holder of a manipulator during an operation.

10   Published PCT application WO98/25666, filed on December 10, 1997 and assigned to the present assignee (the full disclosure of which is incorporated herein by reference) describes a Multicomponent Telepresence System and Method which significantly improves the safety and speed with which robotic surgical tools can be removed and replaced during a surgical procedure. While this represents a significant

15   advancement of the art, as is often true, still further improvements would be desirable. In particular, each tool change which occurs during a surgical procedure increases the overall surgery time. While still further improvements in the mechanical tool/manipulator interface may help reduce a portion of this tool change time, work in connection with the present invention has shown that the mechanical removal and

20   replacement of the tool may represent only one portion of the total interruption for a tool change. U.S. Patent No. 5,400,267 describes a memory feature for electrically powered medical equipment, and is also incorporated herein by reference.

As more and more different surgical tools are provided for use with a robotic system, the differences between the tool structures (and the interaction between

25   the tool and the other components of the robotic system) become more pronounced. Many of these surgical tools will have one or more degrees of motion between the surgical end effectors and the proximal interface which engages the tool to the holder of the manipulator. The desired and/or practicable ranges of motion for an electrosurgical scalpel may be significantly different than those of a clip applier, for example. Work in

30   connection with the present invention has found that even after a tool is properly placed on the surgical manipulator, the time involved in reconfiguring the robotic system to take advantage of a different tool, and to perfect the master controller's effective control over the degrees of motion of the tool, may add significantly to the total tool change delay.

In light of the above, it would be desirable to provide improved robotic surgery tools, systems, and method. It would further be desirable to provide techniques for reducing the total delay associated with each tool change. It would be especially desirable if these enhanced, and often more rapid, robotic tool change techniques resulted

5   in still further improvement in the safety and reliability of these promising surgical systems.

SUMMARY OF THE INVENTION

The present invention generally provides improved robotic surgical devices, systems, and methods for preparing for and performing robotic surgery. The

10   robotic tools of the present invention will often make use of a memory structure mounted on a tool, manipulator arm, or movable support structure. The memory can, for example, perform a number of important functions when a tool is loaded on the tool manipulator: first, the memory can provide a signal verifying that the tool is compatible with that particular robotic system. Secondly, the tool memory may identify the tool-type (whether

15   it is a scalpel, needle grasper, jaws, scissors, clip applier, electrocautery blade, or the like) to the robotic system so that the robotic system can reconfigure its programming to take full advantage of the tools' specialized capabilities. This tool-type data may simply be an identification signal referencing further data in a look-up table of the robotic system. Alternatively, the tool-type signal provided by the tool may define the tool characteristics

20   in sufficient detail to allow reconfiguration of the robotic programming without having to resort to an external table. Thirdly, the memory of the tool may indicate tool-specific information, including (for example) measured calibration offsets indicating misalignment between the tool drive system and the tool end effector elements, tool life data (such as the number of times the tool has been loaded onto a surgical system, the

25   number of surgical procedures performed with the tool, and/or the total time the tools has been used), or the like. The information may be stored in some form of non-volatile memory such as one-time programmable EPROM, Flash EPROM, EEPROM, battery-backed-up SRAM, or similar memory technology where data can be updated and retained in either a serial or random access method, or with any of a wide variety of alternative

30   hardware, firmware, or software. The invention further provides improved engagement structures for coupling robotic surgical tools with manipulator structures.

In a first aspect, the invention provides a robotic surgical tool for use in a robotic surgical system. The robotic surgical system has a processor which directs

movement of a tool holder. The tool comprises a probe having a proximal end and a distal end. A surgical end effector is disposed adjacent the distal end of the probe. An interface is disposed adjacent to the proximal end of the probe. The interface can be releasably coupled with the tool holder. Circuitry is mounted on the probe. The circuitry defines a signal for transmitting to the processor so as to indicate compatibility of the tool with the system.

The tool will often comprise a surgical instrument suitable for manipulating tissue, an endoscope or other image capture device, or the like. Preferably, the signal will comprise unique tool identifier data. The processor of the robotic surgical system may include programming to manipulate the tool identifier according to a pre-determined function or algorithm so as to derive verification data. The signal transmitted to the processor will often include the verification data. Alternative compatibility signals may include a signal which is listed in a table accessible to the processor, an arbitrary compatibility data string, or the like.

In another aspect, the invention provides a robotic surgical component for use in a robotic surgical system having a processor and a component holder. The component comprises a component body having an interface mountable to the component holder. The body supports a surgical end effector, and a drive system is coupled to the body for moving the end effector per commands from the processor. Circuitry is mounted on the body and defines a signal for transmitting to the processor. The signal may indicate compatibility of the component with the system, may define a component type of the component, may indicate coupling of the component to the system, and/or may indicate calibration of the component. Typically, the component will comprise a surgical tool, a manipulator arm, a pre-positioning linkage supporting the manipulator arm, or the like.

In another aspect, the invention provides a method for installing a robotic surgical component in a robotic surgical system. The method comprises mounting the component to a component holder. A signal is transmitted from the component to a processor of the robotic surgical system. The component is articulated in response to the signal per commands of the processor.

In many embodiments, compatibility of the component with the robotic surgical system will be verified using the signal transmitted from the component to the processor. This can be accomplished by providing unique identification data on the component, and deriving verification data from the identification data according to an

algorithm. The verification data is stored with a memory of the component, the signal transmitted to the processor including both the identification and verification data. The algorithm may then be performed on the transmitted unique identification data with the processor, and the results compared with the verification data. Advantageously, this method can take advantage of unique identification data which is often unalterably stored in a memory of commercially available integrated circuits.

In another aspect, the invention provides a robotic surgical tool for use in robotic surgical systems having a processor. The tool comprises a shaft having a proximal end and a distal end. A surgical end effector is disposed adjacent the distal end of the shaft. The end effector has a plurality of degrees of motion relative to the proximal end. An interface is disposed adjacent the proximal end of the shaft. The interface can be releasably coupled with a robotic probe holder. The interface comprises a plurality of driven elements. A plurality of tool drive systems couple the driven elements to the degrees of motion of the end effector. The tool drive system has calibration offsets between a nominal relative position of the end effector and the driven elements, and a measured relative position of the end effector and driven elements. A memory stores data indicating the offsets. The memory is coupled to the interface so as to transmit the offsets to the processor.

In yet another aspect, the invention provides a robotic surgical system comprising a plurality of tools of different tool-types. Each tool comprises an elongate shaft with a cross-section suitable for introduction into an internal surgical site within a patient body via a minimally invasive opening. A distal surgical end effector is coupled to the shaft by at least one joint. The joint is drivingly coupled to a proximal interface by a tool drive system. Circuitry of the tool transmits a tool-type via the interface. The tool types may optionally differ in at least one characteristic such as joint geometry, end effector geometry, drive system characteristics, end effector or drive system strength, or the like. The system also includes a robotic manipulator including a linkage supporting a tool holder. The tool holder releasably receives the interface. A manipulator drive motor drivingly engages the linkage so as to move the tool holder relative to the opening and position the shaft within the surgical site. A tool drive motor is coupled to the tool holder so as to drivingly engage the tool drive system and articulate the joint. A processor is coupled to the tool holder. The processor has programming that effects a desired movement of the end effector by transmitting drive signals to the tool drive motors of the

manipulator. The processor reconfigures the program for the different joint geometries based on the tool-type signals.

In another aspect, the invention provides a robotic surgical system comprising a surgical tool having a surgical end effector and an interface. A manipulator assembly has a base and a tool holder for releasably engaging the interface. A plurality of tool engagement sensors are coupled to the tool holder. Each tool sensor produces a signal when the interface engages the holder. A processor is coupled to the tool engagement sensors. The processor has a tool change mode and a tissue manipulation mode. The processor requires tool signals from each of the sensors before changing the tool change mode to the tissue manipulation mode. The processor remains in the tissue manipulation mode when at least one, but not all, of the tool signals is lost.

The tools used in robotic surgery will be subjected to significant structural stress during use. The stress may result in temporary loss of an engagement signal from an engagement sensor. By providing at least two, and preferably three engagement sensors, the surgical procedure can continue safely with the loss of an engagement signal from an individual sensor so long as the system can still verify proper engagement between the manipulator and tool. This arrangement results in a robust tool engagement sensing system that avoids frequent delays during the surgical procedure as might occur from the loss of an individual signal.

In yet another aspect, the invention provides a robotic surgical system comprising a manipulator assembly having a base and tool holder which moves relative to the base. The tool holder has a plurality of drive elements. A sterile drape covers at least a portion of the manipulator. A sterile tool has a proximal interface and distal end effector. The distal end effector has a plurality of degrees of motion relative to the proximal interface. The degrees of motion are coupled to drive elements of the interface. An adapter is disposed adjacent the sterile drape between the holder and the interface. The adapter comprises a plurality of movable bodies. Each movable body has a first surface driven by the drive elements of the holder, and a second surface driving the driven elements of the tool.

In yet another aspect, the invention provides a robotic surgical tool for use with a robotic manipulator having a tool holder. The tool holder has magnetically actuatable circuitry. The tool comprises a probe having a proximal end and a distal end. A surgical end effector is disposed adjacent the distal end of the probe. An interface

adjacent the proximal end of the probe is releasably coupleable with the holder. The interface comprises a magnet positioned so as to actuate the circuitry of the holder.

BRIEF DESCRIPTION OF THE DRAWINGS

5   Fig. 1 illustrates a robotic surgical procedure in which a surgeon at a master station directs movement of robotic surgical tools effected by a slave manipulator, and shows an assistant preparing to change a tool mounted to a tool holder of the slave.

Fig. 2 is a perspective view of a robotic surgical arm cart system in which a series of passive set-up joints support robotically actuated manipulators (typically, the

10   center arm would support a camera).

Fig. 2A is a perspective view of a robotic surgical manipulator for use in the cart system of Fig. 2.

Figs. 2B and C are side and front views, respectively, of the linkage of the robotic manipulator of Fig. 2, showing how the manipulator maintains a remote center of

15   rotation along a shaft of the surgical tool.

Figs. 3 and 3A are perspective views of exemplary cart structures with positioning linkages which support the robotic manipulators in the system of Fig. 2.

Fig. 4 is a perspective view of an exemplary tool according to the principles of the present invention.

20   Figs. 4A and B are schematic views of alternative drive systems for the tool of Fig. 4.

Figs. 5A through H are illustrations of a variety of surgical end effectors of differing tool-types.

Fig. 6 illustrates the mechanical and electrical interface of the tool of

25   Fig. 4.

Figs. 7A through E illustrate an adapter for coupling the interface of Fig. 6 to the surgical manipulator.

Figs. 7G through I illustrate the adapter of Figs. 7A through E mounted to a holder or carriage of the manipulator.

30   Figs. 7J through L illustrate the holder, its driving elements, and its electrical contacts.

Fig. 8 is a wiring diagram for the tool of Fig. 4, the adapter of Fig. 7A-E, and related components of the robotic system.

Figs. 8A and B are rear and front views of the master console, respectively.

Fig. 9 is a functional block diagram schematically illustrating the signal path hardware of the tool change system.

Fig. 10 is a schematic diagram illustrating the interaction between the software modules related to tool change.

Fig. 11 is a logic flow chart illustrating an exemplary method for sensing engagement of a tool with the manipulator.

Fig. 12 is a flow diagram illustrating how the tool engagement signals are used to change the operating state of the robotic system.

Fig. 13 illustrates the tool engagement method steps initiated by the processor in response to a change in operating state during tool changes.

Figs. 14A through C illustrate mounting of the adapter of Figs. 7A through E to a manipulator arm, and of mounting the tool of Fig. 4 onto the adapter.

Fig. 15 schematically illustrates an exemplary tool compatibility verification algorithm according to the principles of the present invention.

DESCRIPTION OF THE SPECIFIC EMBODIMENTS

The present invention provides robotic surgery systems, devices, and methods. Robotic surgery will generally involve the use of multiple robotic arms. One or more of the robotic arms will often support a surgical tool which may be articulated (such as jaws, scissors, graspers, needle holders, microdissectors, staple appliers, tackers, suction/irrigation tools, clip appliers, or the like) or non-articulated (such as cutting blades, cautery probes, irrigators, catheters, suction orifices, or the like). One or more of the robotic arms will often be used to support one or more surgical image capture devices such as an endoscope (which may be any of the variety of structures such as a laparoscope, an arthroscope, a hysteroscope, or the like), or optionally, some other imaging modality (such as ultrasound, fluoroscopy, magnetic resonance imaging, or the like). Typically, the robotic arms will support at least two surgical tools corresponding to the two hands of a surgeon and one optical image capture device.

The present invention will find application in a variety of surgical procedures. The most immediate applications will be to improve existing minimally invasive surgical procedures, such as coronary artery bypass grafting and mitral and

aortic valve repair and/or replacement. The invention will also have applications for surgical procedures which are difficult to perform using existing minimally invasive techniques, such as Nissen Fundoplications. Additionally, it is anticipated that these surgical systems will find uses in entirely new surgeries that would be difficult and/or

5   impossible to perform using traditionally open or known minimally invasive techniques. For example, by synchronizing the movements of the image capture device and/or surgical tools with a tissue undergoing physiological movement (such a beating heart), the moving tissue may be accurately manipulated and treated without halting the physiological movement. Additional potential applications include vascular surgery

10   (such as for the repair of thoracic and abdominal aneurysms), general and digestive surgeries (such as cholecystectomy, inguinal hernia repair, colon resection, and the like), gynecology (for fertility procedures, hysterectomies, and the like), and a wide variety of alternative procedures.

        Referring now to Fig. 1, the robotic surgical system 10 generally includes

15   master controller 150 and a robotic arm slave cart 50. Master controller 150 generally includes master controllers (not shown) which are grasped by the surgeon and manipulated in space while the surgeon views the procedure views a stereo display. The master controllers are manual input devices which preferably move with six degrees of freedom, and which often further have an actuatable handle for actuating tools (for

20   example, for closing grasping saws, applying an electrical potential to an electrode, or the like). In this embodiment, the master control station 150 also includes a processor, as will be described in more detail hereinbelow.

        Robotic arm cart 50 is positioned adjacent to patient body P and moves tools having shafts. The shafts extend into an internal surgical site within the patient

25   body via openings O. As illustrated in Fig. 1, one or more assistant may be present during surgery to assist the surgeon, particularly during removal and replacement of tools. Robotic surgery systems and methods are further described in co-pending U.S. patent application No. 08/975,617, filed November 21, 1997, the full disclosure of which is incorporated herein by reference.

30   Robotic arm cart 50 is shown in isolation in Fig. 2. Cart 50 includes a base 52 from which three surgical tools 54 are supported. More specifically, tools 54 are each supported by a series of manually articulatable linkages, generally referred to as set-up joints 56, and a robotic manipulator 58. It should be noted that these structures are here illustrated with protective covers extending over much of the robotic linkage. It should

be understood that these protective covers are optional, and may be limited in size or entirely eliminated in some embodiments to minimize the inertia that is manipulated by the servo mechanism, to limit the volume of moving components so as to avoid collisions, and to limit the overall weight of cart 50.

Cart 50 will generally have dimensions suitable for transporting the cart between operating rooms. The cart will typically fit through standard operating room doors and onto standard hospital elevators. The cart should have a weight and wheel (or other transportation) system that allows the cart to be positioned adjacent an operating table by a single attendant. The cart should have sufficient stability in the transport configuration to avoid tipping at minor discontinuities of the floor, and to easily withstand overturning moments that will be imposed at the ends of the robotic arms during use.

Referring now to Figs. 2A-C, robotic manipulators 58 preferably include a linkage 62 that constrains movement of tool 54. More specifically, linkage 62 includes rigid links coupled together by rotational joints in a parallelogram arrangement so that tool 54 rotates around a point in space 64, as more fully described in issued U.S. Patent No. 5,817,084, the full disclosure of which is incorporated herein by reference. The parallelogram arrangement constrains rotation to pivoting about an axis 64a, sometimes called the pitch axis. The links supporting the parallelogram linkage are pivotally mounted to set-up joints 56 so that tool 54 further rotates about an axis 64b, sometimes called the yaw axis. The pitch and yaw axes intersect at the remote center 64, which is aligned along a shaft 66 of tool 54.

Tool 54 has still further driven degrees of freedom as supported by manipulator 58, including sliding motion of the tool along insertion axis 64 (the axis of shaft 66), sometimes referred to as insertion. As tool 54 slides along axis 64c relative to manipulator 58, remote center 64 remains fixed relative to base 68 of manipulator 58. Hence, the entire manipulator is generally moved to re-position remote center 64.

Linkage 62 of manipulator 58 is driven by a series of motors 70. These motors actively move linkage 62 in response to commands from a processor. Motors 70 are further coupled to tool 54 so as to rotate the tool about axis 66, and often to articulate a wrist at the distal end of the tool about at least one, and often two, degrees of freedom. Additionally, motors 70 can be used to actuate an articulatable end effector of the tool for grasping tissues in the jaws of a forceps or the like. Motors 70 may be coupled to at least some of the joints of tool 54 using cables, as more fully described in U.S. Patent No. 5,792,135, the full disclosure of which is also incorporated herein by reference. As

described in that reference, the manipulator will often include flexible members for transferring motion from the drive components to the surgical tool. For endoscopic procedures, manipulator 58 will often include a cannula 72. Cannula 72 supports tool 54, allowing the tool to rotate and move axially through the central bore of the cannula.

As described above, manipulator 58 is generally supported by passive set-up joints 56. Exemplary set-up joint structures are illustrated in Fig. 3. The exemplary set-up joint system includes three types of structures. First, a vertical column 80 supports vertically sliding joints 82 that are used to position manipulator 58 along the vertical or Z axis. Second, rotary joints 84 separated by rigid links 86 are used to horizontally position manipulators 58 in the X-Y plane. Third, another series of rotary joints 84 mounted adjacent a manipulator interface 88 rotationally orients the manipulators.

The structure of column 80, vertical sliding joints 82, and base 52 can be understood with reference to Fig. 3. Beginning with base 52, the base will generally distribute the weight of the robotic structures and the forces imposed on the robotic arms. Column 80 extends upward from base 52, and may optionally comprise a box steel structure. Sliding joints 82 are counterbalanced by weights mounted with column 80. Sensors (typically in the form of potentiometers) indicate vertical position of slider joints 82, and also indicate the rotational position of each rotary joint 84. As the structure of the joint elements is known, the processor can accurately determine the position and orientation of the manipulator base. As the position of the tool and tool end effector will be known relative to the manipulator base, the processor can further accurately determine end effector position and orientation, as well as how to effect movement in a desired direction by articulating one or more the driven joints.

Each of rotational joints 84 and slider joints 82 includes a brake. The brake prevents articulation about the joint unless the brake is released, the brake being normally on. The brakes at all the joints are actuated in unison by a button on the set-up joints, thereby allowing the operating room personnel to position the manipulator in space when the brake is released. Additional rotational joints similarly allow the orientation of the manipulator to be set while the brake is released. The exemplary set-up joint structure is more fully described in co-pending application serial No. 09/368,309, filed August 3, 1999, the full disclosure of which is incorporated herein by reference.

An alternative set-up joint structure is illustrated in Fig. 3A. In this embodiment, an endoscope 55 is supported by an alternative manipulator structure 58' between two tissue manipulation tools. It should be understood that the present invention

·may incorporate a wide variety of alternative robotic structures, including those described in U.S. Patent No. 5,878,193, the full disclosure of which is incorporated herein by reference. Additionally, while the data communication between a robotic component and the processor of the robotic surgical system is primarily described herein with reference to communication between tool 54 and the processor of the robotic surgical system, it should be understood that similar communication may take place between circuitry of a manipulator, a set-up joint, an endoscope or other image capture device, or the like, and the processor of the robotic surgical system for component compatibility verification, component-type identification, component calibration (such as off-set or the like) communication, confirmation of coupling of the component to the robotic surgical system, or the like.

An exemplary tool 54 is illustrated more clearly in Fig. 4. Tool 54 generally includes a rigid shaft 102 having a proximal end 104 and distal end 106. A proximal housing 108 includes an interface 110 which mechanically and electrically couples tool 54 to the manipulator. A surgical end effector 112 is coupled to shaft 102 by a wrist joint 114 providing at least 1 degree of freedom, and ideally providing at least 2 degrees of freedom.

As illustrated in Fig. 4A, a drive system 116 mechanically couples first and second end effector elements 112a, 112b to driven elements 118 of interface 110. Drive system 116 is more fully described in U.S. Patent No. 5,792,135, the full disclosure of which is incorporated herein by reference. Stated simply, the drive system translates mechanical inputs from driven elements 118 into articulation of the wrist about first and second axes A1, A2, as well as into actuation of the two element end effector by relative movement of the end effector elements about axis A2. In addition, driven elements 118 can effect rotation of the end effector about the axis of shaft 102 (A3) by rotating the shaft relative to proximal housing 108, and allowing the cables to twist (within a limited angular range) within the shaft.

A wide variety of alternative drive systems might be employed, including alternative cabling arrangements, drive chains or belts, hydraulic drive systems, gear trains, or the like. In some of these drive systems, motion of end effector 112 about the axes may be coupled to multiple driven elements 118. In other embodiments, there may be a one to one correspondence between driven elements 118 and motion of an end effector element about an axis. Still other embodiments may require fewer (or more) driven elements to effect the desired degrees of freedom, for example, when a single

element end effector is provided. Hence, manipulation of the end effector via interface 110 will generally involve some reconfiguration of the robotic system during the tool change. One alternative drive system 116' is shown in Fig. 4B.

Exemplary wrist structures and surgical end effectors are illustrated in more detail in Figs. 5A and 5B. A Potts scissor is illustrated in Fig. 5A, while a 15 degree scalpel electrically coupled to a conductor 120 for electrosurgery is illustrated in Fig. 5B. These different tool-types have wrists 114 which may have differing separation distances between their axes A1, A2, differing range of motions about each axes, different joint binding positions or singularities, and/or other differences in their axial geometries. Additionally, these two different end effector structures will have different strengths, different inertias, different effective gearing ratios between motion about their axes and movement of driven elements 118, and the like. Still further differences between these two tool-types, and/or between either of these tools and tools of other types, include the presence or absence of an electrosurgical capability, the useful life of the tool (in time, procedures, or tool change operations), the ability to replace end effector elements, and the like. It should be understood that alternative wrist joint arrangements are possible.

Still further end effectors for additional different tool-types are illustrated in 5C-5H. Fig. 5C illustrates a DeBakey forceps, while Fig. 5D illustrates a microforceps. Potts scissors are again illustrated in Fig. 5E, and a clip applier is illustrated in Fig. 5F. Another scalpel is illustrated in Fig. 5G, while Fig. 5H illustrates an electrocautery probe. It should be understood that a wide variety of alternative end effectors for differing tool-types may be provided, and that several of these tool-types may be used during a single surgical procedure. Hence, the tools of the present invention may incorporate any of the illustrated end effectors, or any other end effector which is useful for surgery, particularly at an internal surgical site.

Interface 110 of a proximal housing 108 is illustrated in Fig. 6. As seen schematically in Fig. 4A, driven elements 118 provide mechanical coupling of the end effector to drive motors mounted to the manipulator. Driven elements 118 each include a pair of pins 122 extending from a surface of the driven element. An inner pin 122A is closer to an axis of rotation of each driven elements 118 than an outer pin 122B, which helps to ensure positive angular alignment of the driven element. Interface 110 further includes an array of electrical connecting pins 124 coupled to a memory structure 126 by a circuit board within housing 108. In the exemplary embodiment, memory 126 comprises Dallas part No. DS 2505.

Surgical tools 54 will generally be sterile structures, often being sterilizable and/or being provided in hermetically sealed packages for use. In contrast, the complex servo mechanism of cart 50 and manipulator 58 may be difficult and/or impossible to fully sterilize between procedures. Instead, a sterile drape will often cover

5   at least a portion of the cart and manipulator structures to maintain the sterile environment around the patient.

As tools 54 will be removed and replaced repeatedly during many procedures, the tool holder could potentially be exposed to contamination if the interface directly engages the tool holder. To avoid contamination of the tool holder and possible

10   cross contamination between patients, the present invention provides an adaptor for coupling interface 110 to the tool holder of the manipulator assembly.

White interface 110 is described herein with reference to mechanical, electrical, and magnetic coupling elements, it should be understood that a wide variety of telemetry modalities might be used, including infrared, inductive coupling, or the like.

15   Referring to Figs. 7A-7E, adaptor 128 generally includes a tool side 130 and a holder side 132. A plurality of rotatable bodies 134 are mounted to a floating plate 136 which has a limited range of movement relative to the surrounding adaptor structure normal to the major surfaces of the adaptor. Axial movement of the floating plate helps decouple the rotatable bodies from the tool when the levers along the sides of housing

20   108 are actuated (See Fig. 4).

Rotatable bodies 134 are resiliently mounted to floating plate 136 by resilient radial members which extend into a circumferential indentation about the rotatable bodies. The rotatable bodies can move axially relative to plate 136 by deflection of these resilient structures.

25   When disposed in a first axial position (toward tool side 132) the rotatable bodies are free to rotate without angular limitation. However, as the rotatable bodies move axially toward tool side 130, tabs 138 (extending radially from the rotatable bodies) laterally engage detents on the floating plates so as to limit angular rotation of the rotatable bodies about their axes. This limited rotation can be used to help drivingly

30   engage the rotatable bodies with drive pins of the holder, as the drive pins will push the rotatable bodies into the limited rotation position until the pins are aligned with (and slide into) openings 140.

Openings 140 on the tool side 130 and holder side 132 of rotatable bodies 134 are configured to accurately align the driven elements 118 of the tool with the drive

elements of the holder. As described above regarding inner and outer pins 122A, 122B of driven elements 118, the openings 140 in each side of each rotatable body are at differing distances from the axis of rotation so as to ensure that the alignment is not 180° from its intended position. Additionally, each of the openings 140 is slightly radially elongate so as to fittingly receive the pins in the circumferential orientation. This allows the pins to slide radially within the openings and accommodate some axial misalignment between the tool and holder, while minimizing any angular misalignment and backlash between the drive and driven elements. Openings 140 on the tool side 132 are offset by about 90° from the openings on the holder side, as can be seen most clearly in Fig. 7C.

Holder side of adaptor 128 includes another array of electrical connector pins 124, and the tool side 132 of the adaptor includes slots 142 for receiving the pin array from the tool (as illustrated in Fig. 6). In addition to transmitting electrical signals between the tool and holder, at least some of these electrical connections are coupled to an adaptor memory device 144 by a circuit board of the adaptor. A latch 145 releasably affixes the adaptor to the holder. A lip on the tool side 130 of adaptor 128 slidably receives laterally extending tabs of housing 108 adjacent to interface 110. The interaction between pins 122 and openings 140 helps restrain the tool in the engaged position until the levers along the sides of the tool housing push the floating plate axially from the interface so as to release the tool. The holder 129 and drive elements 119 are shown (without the adjacent manipulator structure) in Figs. 7F through M.

Referring now to Fig. 8, an exemplary circuit diagram illustrates the coupling of tool memory 126 and adaptor memory 144 to the wiring harness of the manipulator. The electrically coupling of tool memory 126 with the wiring of the manipulator may be used to sense the presence of the tool. Similarly, electrical coupling between the manipulator wiring system and adaptor memory 144 may be used as an adaptor engagement sensor. In the exemplary embodiment, two additional sensors are also provided to determine engagement of the tool and holder: a magnetic reed switch 147 (actuated by a magnet 125 of interface 110), and a electrical coupling short 148 (or alternatively an end-of-life indicator) electrically coupling two of the pins 124 of tool 54. The use of a magnetically actuated sensor mounted to the holder or adapter is particularly advantageous. The tool-mounted magnet will tend to maintain the signal from a magnetic sensor (despite small, stress induced movements of the tool), in part because of the magnetic field effects and/or hysteresis, once contact has been made. Optionally, adapter memory 144 may be read only when no tool is coupled to the adapter by "shorting" the

adapter memory with the magnetic reed switch, so that the adapter is transparent to tool/processor communications after installation is completed.

An exemplary surgeon's workstation is illustrated in Figs. 8A and 8B. Control station 150 includes processors 152 for the robotic circle mechanism. Also included in controller station 150 are a stereo imaging system 154 and a pair of controllers (not shown).

The surgeon will generally manipulate tissues using the robotic system by moving the controllers within a three dimensional controller work space of controller station 150. Processor 152 can calculate an image capture coordinate system via the sensors in setup joints 56 and manipulator 58 supporting the laparoscope, and can perform coordinate system transformations so as to generate signals to the drive motors of the manipulator that maintain alignment between the three dimensional image of the end effectors and the hand controllers within the controller work space. By maintaining this alignment, as the physician moves the hand controller in both position and orientation, the robotic surgery system allows the surgeon to manipulate the surgical tools as if the handle in the surgeon's hand and the end effector in the surgeon's field of view define a single contiguous surgical instrument. This provides an enhanced sense of presence and allows the surgeon to operate efficiently and accurately without performing mental coordinate transformations. The program instructions for effecting these processes may optionally be embodied in a machine readable code stored on a tangible media 153, which may comprise an optical disk, a magnetic disk, a magnetic tape, a bar code, EEPROM, or the like. Alternatively, programming instructions may be transmitted to and from processor 152 using data communications systems such as an IO cable, an intranet, the internet, or the like. An exemplary control system is described in more detail in co-pending U.S. Patent Application Serial No. 09/373,678, filed August 13, 1999, for a Camera Referenced Cartesian Control System, the full disclosure of which is incorporated herein by reference.

The tool/adaptor hardware signal path is schematically illustrated in Fig. 9. Processor 152 of master control station 150 comprises multiple separate processor boards supported by a chassis. In the exemplary embodiment, a control and transform processor CTP handles calculation of the coordinate system transforms for generating the proper instruction signals to send to servo motors. The control and transform processor CTP may comprise an Analog Device ADSP 21060 digital signal processor, or a wide variety of alternative commercially available processors. A master diagnostic controller MDC

monitors and verifies the health of the processing and servo mechanical system. In the exemplary embodiment, the master diagnostic controller MDC comprises a Dallas DS 87C530 processor. A Dallas DS 87C520 processor is used as the user interface master controller UMC to handle the input and output to and from the surgeon seated at the

5   console. Once again, these functions may alternatively be performed by a variety of commercially available processors. Hence, processor 152 may include a single processor, or a number of distinct processor structures coupled together, ideally in a distributed processing arrangement.

In the exemplary distributed processing arrangement shown in Fig. 9,

10 processor 152 makes use of a remote printed circuit assembly ("PCA") referred to as the remote interface adaptor RIA, which is coupled to the chassis by a wiring harness. A remote interface adaptor RIA is provided for each of the robotic arms of the system, typically including one PCA for the endoscope and two PCA's for the two surgical end effectors. The remote interface adaptor RIA also comprises a Dallas DS 87C 520

15 processor and couples the processor 152 to the holder or carriage of manipulator 58. The RIAs 56 perform local processing for the manipulators, set-up joints, and/or tools, and communicate with processor 152 using a high-level language. Manipulator 58 is, in turn, coupled to tool 54 by adaptor 128 as described above.

It should be noted that reed switch 147 may actually be mounted on

20 carriage of manipulator 58, and may be actuated by a magnet mounted on the tool 54. Hence, reed switch 147 ensures that tool 54 is positioned in the holder of manipulator 58, the reed switch acting as a tool sensor. Electrical coupling of the tool memory 126 and an electrical loop-back circuit 149 connecting pins of tool 54 each act as additional independent tool sensors. Optionally, an end-of-use detector such as a low resistance

25 timed fuse, or the like, may change an electrical characteristic of the loop-back circuit to disqualify tools past the end of their safe lives. An expired tool may provide an indication to the system operator such as a pop-up flag, a color-change spot, or the like, to indicate the tool is at or near the end of its life. Optionally, a portable life indication device may be coupled to the tools before each procedure to determine if the tool has

30 sufficient life to be used for the planned procedure.

A variety of alternative end of use indication systems might be provided to indicate that a tool is near or at the end of its useful life. For example a mechanical end of use indicator may be mounted in housing 108, such as a colored button or tab which can pivot into view through an indication window of the housing. Such a button might be

biased toward the viewable position, and initially held out of sight by a latch. The latch might be releasable by an actuator mounted to the carriage of manipulator 58, for example, by the movement of a plunger of a solenoid on the manipulator. The sterile adapter or drape will preferably accommodate movement of such a plunger while

5   maintaining sterile separation between the manipulator and tool. In general, providing a mechanical indicator on the tool for actuation by an actuation means of the manipulator can avoid the cost for end of use actuators mounted on each tool.

Referring now to Fig. 10, the flow of the tool signals from the tool sensors during a tool change operation originates from the interaction between the remote

10   interface adaptor RIA and the tool itself. The tool signals are transmitted per procedure management/data handler programming running on the master diagnostic controller MDC. The overall logic flow proceeds according to a supervisor program running on the user interface master control UMC according to the surgeon's input from the master console.

15   The supervisor directs the state of the robotic arms, and also perfects coupling between a mounted tool 54 and the holder of a manipulator by driving the servo motors in a predetermined manner, as shall be explained below. The supervisor software directs movement of the tool through a middleman program running on the control and transform processor CTP. The middleman program accepts instructions from the

20   supervisor to move the surgical end effectors in the desired direction, for example, and calculates the drive signals to be provided to the servo motors so as to effect that desired motion. In other words, the middleman program transforms the workstation space instruction into a joint space servo signal set for the servo motors to drive the end effectors.

25   It should be understood that the coordinate transformations used by the middleman to calculate the required servo signals will vary as the relationship between the field of view from the endoscope and the surgical end effectors varies. Deriving these coordinate transformations is well described in the patent literature, for example, in U.S. Patent No. 5,696,837 and U.S. Patent Application Serial No. 09/373,678, the full

30   disclosures of which are incorporated herein by reference. In the control method illustrated in Fig. 10, a Kernel program running on the control and transform processor CTP and Compute Engine processors CE's derives these transformations based on the information provided by the position sensors at the setup joints, manipulators, and the like.

Referring now to Figs. 11 and 12, processor 152 changes the operating state of the robotic system based on tool signals from the three tool engagement sensors (reed switch 147, tool memory 126, and end of use/pin short circuit 148) and an adaptor signal sensed by coupling with the adaptor memory 144. In the local tool detection procedure illustrated in Fig. 11 (which is performed at the remote interface adapter RIA with a cycle time of 35 milliseconds) the reed switch and adapter memory are first sensed to check for the presence of the adapter. So long as the adapter is present, the system then checks for the presence of the tool based on coupling with the tool memory 126. The presence or absence of the tool is verified by checking for the end of use or pin short circuit 148 of the tool breadboard. The remote interface adapter RIA transmits the sensed signals from the sensor scan to the master digital controller MDC for use by the Procedure Management/Data Handler software.

As can be understood with reference to Fig. 12, if the sterile adapter is not sensed (either upon start up or while the tool is removed), the robotic system remains in a sterile adapter off operating state S1. Once the sensor scan indicates that adapter 128 is present, program management data handler advances the operating state to a second operating state S2 in which the system is awaiting engagement of interface 110 with the holder of the manipulator. If the signal from the adapter memory chip is lost for more than half a second, the system returns to the adapter off state S1.

If at least one signal from the three tool sensors indicates engagement of the tool, the operating state advances to a Tool Being Inserted mode S4, and upon agreement of all three sensors that the tool is fully mounted on the holder, the system enters a Tool Is On operating state S5 in which manipulation of the end effectors by the surgeon may be enabled.

The elongate shafts of tool 54 can induce significant mechanical stresses between interface 110, adapter 128, and the holder of the manipulator. As a result, one or more of the tool signals may be lost at least temporarily. If tissue manipulation were halted each time a tool signal were lost, the operation would be significantly delayed and total risk to the patient would increase. The present system takes advantage of the redundant tool signals by keeping the system in the Tool Is On operating state S5 despite the loss of one or even two tool signals. If the loss of signal persists for more than a threshold time, the signal loss is stored for diagnostic purposes. Nonetheless, the system remains in the operating state, until all three tool signals indicate the tool is removed, at

which point the system drops down to the Tool Is Out operating state S2. This procedure provides a much more robust approach than analyzing each tool signal independently.

Referring now to Fig. 13, the instructions generated by the supervisor software running on the user interface master controller UMC as a result of the changes in state during a tool change procedure will generally follow one of four paths. If the adapter is not present and a tool has been taken off (or no tool and adapter are present at start up), the supervisor notifies the user, for example, by displaying an icon on the stereo display and/or assistance monitor, per path PA. If an adapter has been mounted to the holder and no tool is engaged, the supervisor initiates manipulations of the driving elements of the holder which perfect mechanical coupling of the rotational bodies of adapter 128 with the driving elements of the holder per path PB.

As described in some detail with reference to Figs. 7A through E, rotatable bodies 134 can move axially relative to a floating plate 136. Prior to perfecting mechanical coupling between the holder drive elements and the rotatable bodies, pins of driving elements (which are similar in configuration to the driven elements 118 of interface 110) will push the rotatable bodies away from holder side 132 of adapter 128 and toward tool side 130. In this rotationally limited axial position, tabs 138 of rotatable bodies 134 engage detents of the floating plate so as to prevent rotation of more than about 90°. This can ensure that the pins of the driving elements rotate relative to the rotatable bodies by driving the servo motors of the manipulator by more than 90°.

In the exemplary tool change engagement path PB, the servo motors of the manipulator are driven from a starting central position so as to rotate the drive elements by 180° in a first direction (for example, clockwise) in step ENGAGESA1. As the pins of the driving elements will only enter opening 140 of rotatable bodies 134 in a single angular orientation, it is possible that this step will be insufficient to perfect mechanical coupling. To ensure that coupling is complete, the supervisor therefore initiates rotation of the servo motors so as to turn the driving the elements by 360° in the opposite direction (in our example, counterclockwise) in step ENGAGESA2. At some point during the above two steps, pins 122 of the driving elements will be aligned with openings 144 of rotatable bodies 134 and the openings will receive the pins, thereby allowing the rotatable body to move axially to the freely rotatable position. The driving elements in rotatable bodies are then centered in their range of angular travel in step ENGAGESA3.

Once the steps of path PB have been performed so as to perfect mechanical coupling of the driving elements of the holder with the rotatable bodies of the

adapter 128, the supervisor directs the system to perform the procedure outlined by the second part of path PB. Basically, the driving elements (and rotatable bodies) are centered and centering is verified in preparation for mounting of a tool to the holder by rotating the servos right to their end of travel, left, and then halfway between under steps

5   TOOLPREP1, 2, and 3, respectively. These centering and verification steps are also performed if a tool has been removed from the holder, per path PC.

In the final alternative procedure which will be described with reference to Figs. 13, mounting of a tool on the adapter and holder results in the steps outlined in path PD. First, the system verifies that the tool is of the type which is allowable for use on this

10   particular robotic surgical system. To determine compatibility, circuitry of the tool may send a signal indicating the tool-type to processor 152. More specifically, data stored in tool memory 148 may be transmitted to the processor. In the exemplary embodiment, the data from the tool memory will include a character string indicating tool compatibility with the robotic system. Additionally, the data from the tool memory will often include a

15   tool-type. In some embodiments, the data will also include tool offset calibration information. This data may be provided from the tool memory 148 in response to a request signal from the processor 152. A simplified version of path PD is performed if a camera is changed, as shown.

Tool-type data will generally indicate what kind of tool has been attached

20   in a tool change operation. For example, the tool-type data might indicate that Potts scissors or a scalpel has been attached to the holder. The tool-type data may include information on wrist axis geometries, tool strengths, grip force, the range of motion of each joint, singularities in the joint motion space, the maximum force to be applied via driven elements 118, the tool transmission system characteristics including information

25   regarding the coupling of driven elements 118 to articulation of an associated (or the interacting plurality of associated) joint motion, servo gains, end effector elements speeds, and the like.

Tool-type data may optionally be stored in memory of the robotic system. The signal from the tool may comprise an identifier referencing the relevant portion of

30   data from the look-up table. This tool-type data may be loaded into a memory of processor 152 by the system manufacturer, the look-up table preferably being in the form of a flash memory, EEPROM, or the like. As each new tool-type is provided, the robotic system manufacturer can then revise the look-up table to accommodate the new tool-specific information. It should be recognized that the use of tools which are not

compatible with the robotic surgery system, for example, which do not have the appropriate tool-type data in an information table, could result in inadequate robotic control over the end effector by both processor 152 and the surgeon.

In addition to the tool-type data indicated by the signals from tool 54, tool specific information may be stored in the tool memory 148 for reconfiguring the programming of processor 152. For example, there will often be some measurable misalignment or offset between and intended relationship between the wrist joint and end effector elements and the positions of driven elements 118. To accommodate this misalignment without degrading the accuracy of the robotic control over the end effectors, the measured offsets may be stored in the tool memory and factored into the transforms generated by the Kernel. Hence, the storing of such calibration information can be used to overcome minor mechanical inconsistencies between tools of a single type. As described above, tool life and cumulative tool use information may also be stored on the tool memory and used by the processor to determine if the tool is still safe for use. Total tool life may be measured by clock time, by procedure, by the number of times the tool has been loaded onto a holder, and even by individual numbers of end effector actuations. Tool life data will preferably be stored in the memory of the tool using an irreversible writing process.

To perfect mechanical coupling between the driving elements of the holder (and the previously coupled rotatable bodies 134 of adapter 128), the supervisor initiates a "turn one way, turn the other way, and center" operation similar to that described above. To limit the range of motion of driven elements 118 and ensure pins 122 enter openings 140 of adapter 128, the holder may move axially to a proximal position so that the end effector is disposed within cannula 72 of manipulator 58 (see Fig. 2B). The axial positioning and rotation (turn, turn, and center) of the end effector are performed under steps ENGAGETOOL1-4, respectively.

The tool-type (and preferably tool-specific) data from tool memory 148 and/or the look-up table is sent to the middleman and/or Kernel software running on the coordinate transformation processor CTP for driving the appropriate coordinate transformations and generating the servo drive signals, as generally described above with reference to Fig. 10. The supervisor may then verify operation of the tool by manipulating the end effector per the calculated transforms, so as to complete the steps of path PD.

Methods for mounting adaptor 128 (together with a sterile drape) to the holder of manipulator 58 can be understood with reference to Figs. 14A and B. Subsequent mounting of tool 54 to adapter 128 generally comprises inserting the surgical end effector distally through cannula 72 and sliding interface 110 of tool 54 into

5   engagement with a mounted adapter, as illustrated in Fig. 14C. The tool can be removed and replaced by reversing the tool mounting procedure illustrated in Fig. 14C and mounting an alternative tool in its place.

Referring now to Fig. 15, an exemplary system and method for verifying compatibility of a tool with a robotic surgical system makes use of a unique identification

10   data string that is irreversibly stored on an integrated circuit included in the circuitry of a tool or other component of the robotic surgical system. Advantageously, producers of such integrated circuits can include this unique identification data string on each integrated circuit such that no two integrated circuits include the same identification data. For example, Dallas DS 2505 may include a unique 64 bit identification data string which

15   differs from the data strings of every other circuit of that part number.

The identification data string could be downloaded directly to the processor and compared with a table listing all identification data strings of circuits included in compatible tools. Such a table could then be updated each time additional tools were fabricated or outdated tools were retired.

20   To avoid continuously updating a compatible tool table, a verification data string 164 may be calculated from the unique identification data according to an algorithm 166. Algorithm 166 may be used as an encryption mechanism, typically using an arbitrary function which cannot easily be determined by sampling verification data and identification data from a few tools. Verification data string 164 may then be stored in a

25   memory of the tool or other robotic component during tool production, typically using a non-volatile memory.

When the tool having identification data 162 and verification data 164 is coupled to the robotic surgical system, a signal 168 including these data strings may be transmitted to processor 152 as described above. By including a tangible media with

30   method steps for performing algorithm 166 in a system accessible by processor 152, the processor can also perform the algorithm on the unique identification data so as to derive a conformation data string 170. This can be compared with the verification data, thereby confirming compatibility of the tool with the robotic system. Algorithm 166 may include

any of a wide variety of known encryption algorithms, or may be developed specifically for use in the robotic surgical system of the present invention.

The descriptions given above regarding the exemplary devices, systems, and methods of the present invention are provided by way of an example, and for clarity of understanding. A wide variety of changes, modifications, and adaptations of these specific embodiments will be obvious to those of skill in the art. Hence, the invention is limited solely by the following claims.

WHAT IS CLAIMED IS:

1   1.   A robotic surgical tool for use in a robotic surgical system having a
2   processor which directs movement of a tool holder, the tool comprising:
3   a probe having a proximal end and a distal end;
4   a surgical end effector disposed adjacent the distal end of the probe;
5   an interface disposed adjacent the proximal end of the probe, the interface
6   releasably coupleable with the tool holder; and
7   circuitry mounted on the probe, the circuitry defining a signal for
8   transmitting to the processor so as to indicate compatibility of the tool with the system.

1   2.   The robotic surgical tool of claim 1, further comprising a sterile
2   adapter releasably mounted to the tool holder, the adapter coupling the tool holder to the
3   interface, wherein the circuitry transmits the signal to the processor of the robotic surgical
4   system via the adapter.

1   3.   The robotic surgical tool of claim 1, wherein the signal comprises
2   unique tool identifier data.

1   4.   The robotic surgical tool of claim 3, the processor of the robotic
2   surgical system including programming to manipulate the tool identifier according to a
3   predetermined function so as to derive verification data in response to the tool identifier,
4   wherein the signal transmitted to the processor further comprises the verification data.

1   5.   The robotic surgical tool of claim 1, wherein the signal comprises
2   an identifier signal included in a table accessible to the processor for comparison with the
3   signal, the table comprising a plurality of compatible tool identification signals.

1   6.   The robotic surgical tool of claim 1, wherein the signal comprises
2   an arbitrary compatibility data string.

1   7.   The robotic surgical tool of claim 1, wherein the probe body
2   comprises an elongate shaft suitable for distal insertion via a minimally invasive aperture
3   to an internal surgical site of a patient body.

1   8.   The robotic surgical tool of claim 1, wherein the end effector is
2   adapted for manipulating tissue, and further comprising a wrist joint coupling the end

3   effector to the shaft for varying an orientation of the end effector within the internal

4   surgical site.

1   9.   The robotic surgical tool of claim 1, wherein the end effector

2   defines a field of view, the probe comprising an image capture device.

1   10.   A robotic surgical component for use in a robotic surgical system

2   having a processor and a component holder, the component comprising:

3   a component body having an interface mountable to the component holder,

4   the body supporting a surgical end effector;

5   a drive system coupled to the body, the drive system moving the end

6   effector in response to commands from the processor; and

7   circuitry mounted on the body, the circuitry defining a signal for

8   transmitting to the processor, the signal comprising at least one member selected from the

9   group consisting of compatibility of the component with the system, a component-type of

10   the component, coupling of the component to the system, and calibration of the

11   component.

1   11.   The robotic surgical component of claim 10, wherein the

2   component comprises a tool including a shaft having a proximal end and a distal end, the

3   end effector disposed adjacent the distal end of the shaft, with a plurality of degrees of

4   motion relative to the proximal end of the shaft, and wherein the interface comprises a

5   plurality of driven elements, and further comprising a tool drive system coupling the

6   driven elements to the degrees of motion of the end effector, the tool drive system having

7   one or more calibration offsets between a nominal position of the end effector relative to

8   the driven elements and a measured position of the end effector relative to the driven

9   elements;

10   wherein the circuitry comprises a memory storing data indicating the

11   offsets, the memory coupled to the interface so as to transmit the offsets to the processor.

1   12.   A robotic surgical tool for use in a robotic surgical system having a

2   processor which directs movement of a tool holder, the tool comprising:

3   a probe having a proximal end and a distal end;

4   a surgical end effector disposed adjacent the distal end of the probe;

5   an interface disposed adjacent the proximal end of the probe, the interface

6   releasably coupleable with the tool holder; and

7   circuitry mounted on the probe, the circuitry transmitting a signal via the

8   interface to the processor so as to indicate a tool-type of the tool.

1   13.   The tool of claim 12, further comprising at least one joint disposed

2   between the interface and end effector, the joint defining a joint axis geometry, and

3   wherein the signal indicates the joint geometry of the tool to the processor.

1   14.   The tool of claim 12, wherein the end effector has a strength, and

2   wherein the signal indicates the strength of the end effector to the processor.

1   15.   A robotic surgical tool for use in a robotic surgical system having a

2   processor which directs movement of a tool holder, the tool comprising:

3   a probe having a proximal end and a distal end;

4   a surgical end effector disposed adjacent the distal end of the probe;

5   an interface disposed adjacent the proximal end of the probe, the interface

6   releasably coupleable with the tool holder; and

7   circuitry mounted on the probe, the circuitry transmitting a signal via the

8   interface to the processor so as to indicate tool calibration offsets of the tool.

1   16.   A method for installing a robotic surgical component in a robotic

2   surgical system, the method comprising:

3   mounting the component to a component holder;

4   transmitting a signal from the component to a processor of the robotic

5   surgical system;

6   articulating the component in response to the signal per commands of the

7   processor.

1   17.   The installation method of claim 16, further comprising verifying

2   compatibility of the component with the robotic surgical system using the signal.

1   18.   The installation method of claim 17, wherein the compatibility

2   verification step comprises:

3   providing unique identification data on the component;

4   deriving verification data from the identification data according to an

5   algorithm and storing the verification data in a memory of the component, the signal

6   comprising the identification and verification data;

7   performing the algorithm on the transmitted unique identification data with

8   the processor and comparing the results with the verification data.

1   19.   The installation method of claim 16, further comprising

2   reconfiguring the commands of the processor in response to the signal.

1   20.   The installation method of claim 19, wherein the signal comprises

2   a component-type of the component.

1   21.   The installation method of claim 20, wherein the signal comprises

2   calibration of the component.

1   22.   A robotic surgical system comprising:

2   a plurality of tools of different tool-types, each tool comprising an elongate

3   shaft with a cross section suitable for introduction into an internal surgical site within a

4   patient body via a minimally invasive opening, a distal surgical end effector coupled to

5   the shaft by at least one joint, the joint drivingly coupled to a proximal interface by a tool

6   drive system, and circuitry that transmits a tool-type signal via the interface;

7   a robotic manipulator including a linkage supporting a tool holder which

8   releasably receives the interface, at least one manipulator drive motor drivingly engaging

9   the linkage so as to move the tool holder relative to the opening and position the shaft

10   within the surgical site, and at least one tool drive motor coupled to the tool holder so as

11   to drivingly engage the tool drive system and articulate the at least one joint; and

12   a processor coupled to the tool holder, the processor having programming

13   that effects a desired movement of the end effector by transmitting drive signals to the at

14   least one tool drive motor of the manipulator, wherein the processor reconfigures the

15   program for the different characteristics based on the tool-type signals.

1   23.   The robotic system of claim 22, wherein the drive systems of the

2   different tool-types effect different angular movement about the joints for a given input

3   from the tool drive motors, and wherein the processor reconfigures the program for the

4   different drive system angular movements.

1   24.   A fault tolerant robotic surgical system comprising:

2   a surgical tool having a surgical end effector and an interface;

3   a manipulator assembly having a base and a tool holder for releasably

4   engaging the interface;

5   a plurality of tool engagement sensors coupled to the tool holder, each

6   sensor producing a tool signal when the interface engages the holder; and

7   a processor coupled to the tool engagement sensors, the processor having a

8   tool change mode and a tissue manipulation mode, the processor requiring tool signals

9   from each of the sensors before changing from the tool change mode to the tissue

10   manipulation mode, the processor remaining in the tissue manipulation mode when at

11   least one, but not all, of the tool signals is lost.

1   25.   A robotic surgical system comprising:

2   a manipulator assembly having a base and a tool holder which moves

3   relative to the base, the tool holder having a plurality of drive elements;

4   a sterile drape covering at least a portion of the manipulator;

5   a sterile tool having a proximal interface and a distal end effector, the

6   distal end effector having a plurality of degrees of motion relative to the proximal

7   interface, the degrees of motion coupled to driven elements of the interface; and

8   an adapter disposed adjacent the sterile drape between the holder and the

9   interface, the adapter comprising a plurality of movable bodies, each movable body

10   having a first surface driven by the drive elements and a second surface driving the driven

11   elements.

1   26.   The robotic surgical system of claim 25, wherein the movable

2   bodies are rotatable about an axis between the first and second surfaces, the rotatable

3   bodies movable between first and second axial positions, the rotatable bodies being

4   disposed in the first axial position when the adapter plate is mounted to the manipulator

5   and the rotatable bodies are misaligned with the drive elements, angular rotation of the

6   rotatable bodies being limited when the rotatable bodies are disposed in the first axial

7   position to allow alignment of the drive elements with the rotatable bodies by rotating the

8   drive elements, the rotatable bodies having unlimited angular rotation when the rotatable

9   bodies are aligned with the drive elements and the rotatable bodies are disposed in the

10   second axial position, and wherein each of the driven elements has a limited angular

11   rotation.

1   27.   A robotic surgical tool for use with a robotic manipulator having a

2   tool holder, the tool holder having magnetically actuatable circuitry, the tool comprising;

3   a probe having a proximal end and a distal end;

4   a surgical end effector adjacent the distal end of the probe;

5   an interface adjacent the proximal end of the probe, the interface

6   releasably coupleable with the holder, the interface comprising a magnet positioned so as

7   to actuate the circuitry of the holder.

1   28.   A robotic surgical system comprising:

2   a processor;

3   a tool having a surgical end effector; and

4   a robotic manipulator coupling the tool to the end effector;

5   wherein the processor senses coupling of the tool to the manipulator by at

6   least one member selected from the group consisting of:

7   a signal from a memory circuit of the tool;

8   a signal from a memory circuit of an adapter coupling the tool to the

9   manipulator; and

10   a signal from a magnetic switch that is magnetically actuated by a magnet

11   of the tool.

1   29.   A robotic system comprising:

2   a robotic manipulator having a tool holder, the manipulator moving the

3   holder in response to signals from a processor;

4   a tool having a surgical end effector;

5   an adapter coupling the tool to the holder, the adapter maintaining sterile

6   separation between the tool and holder;

7   a first sensor disposed adjacent the holder, the first sensor transmitting a

8   first signal to the processor in response to coupling of the adapter to the holder; and

9   a second sensor disposed adjacent the holder, the second sensor

10   transmitting a second signal to the processor in response to coupling of the tool to the

11   adapter.

1   30.   The robotic surgical tool of claim 3, wherein the signal further

2   indicates at least one of tool life and cumulative tool use by a measurement selected from

3   the group consisting of calendar date, clock time, number of surgical procedures, number

4   of times the tool has been coupled to the system, and number of end effector actuations.

1   31.   A robotic surgical system comprising:

2   a tool having circuitry containing verification information;

3   a coupler for coupling the tool; and

4   at least one system processor for receiving the verification information

5   from the tool coupled to the coupler, said at least one processor further manipulating the

6   information with an algorithm to produce output information, comparing the output

7   information to predetermined data to verify compatibility of the tool with the robotic

8   surgical system, and enabling the robotic surgical system to manipulate the tool if the

9   output information matches the predetermined data.

1   32.   The system of claim 31, wherein said verification information and

2   said predetermined data are unique to said tool, and said predetermined data are contained

3   in said circuitry on said tool.

FIG - 1

FIG 2

FIG_2A

58

122

119

64a

62

62

62

62

72

62

646

70

70'

68

FIG - 2B

62

72

64

62

FIG - 2C

FIG_3

Fig - 3A

FIG_4A

FIG_4

FIG-4B

FIG 5A

FIG 5B
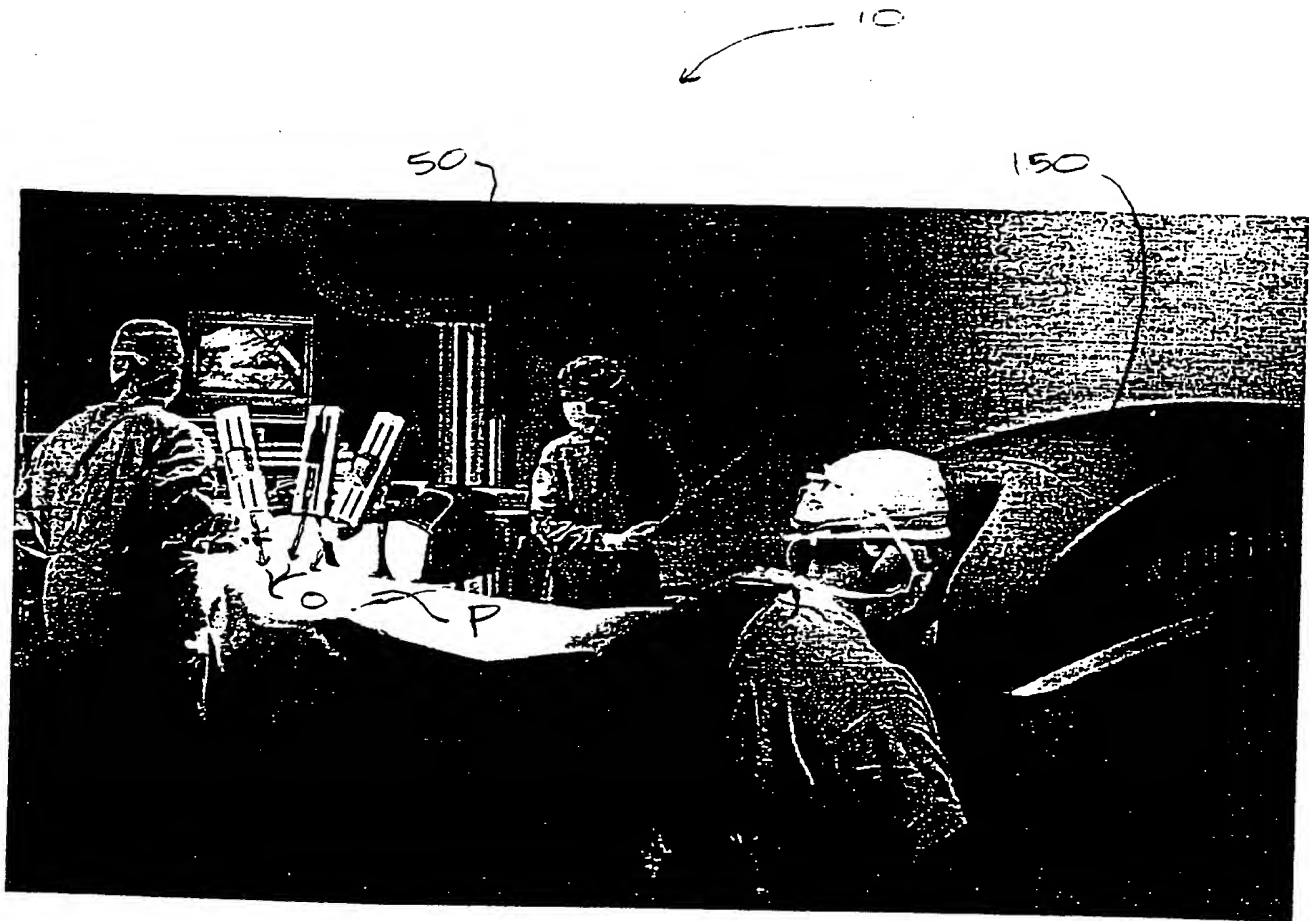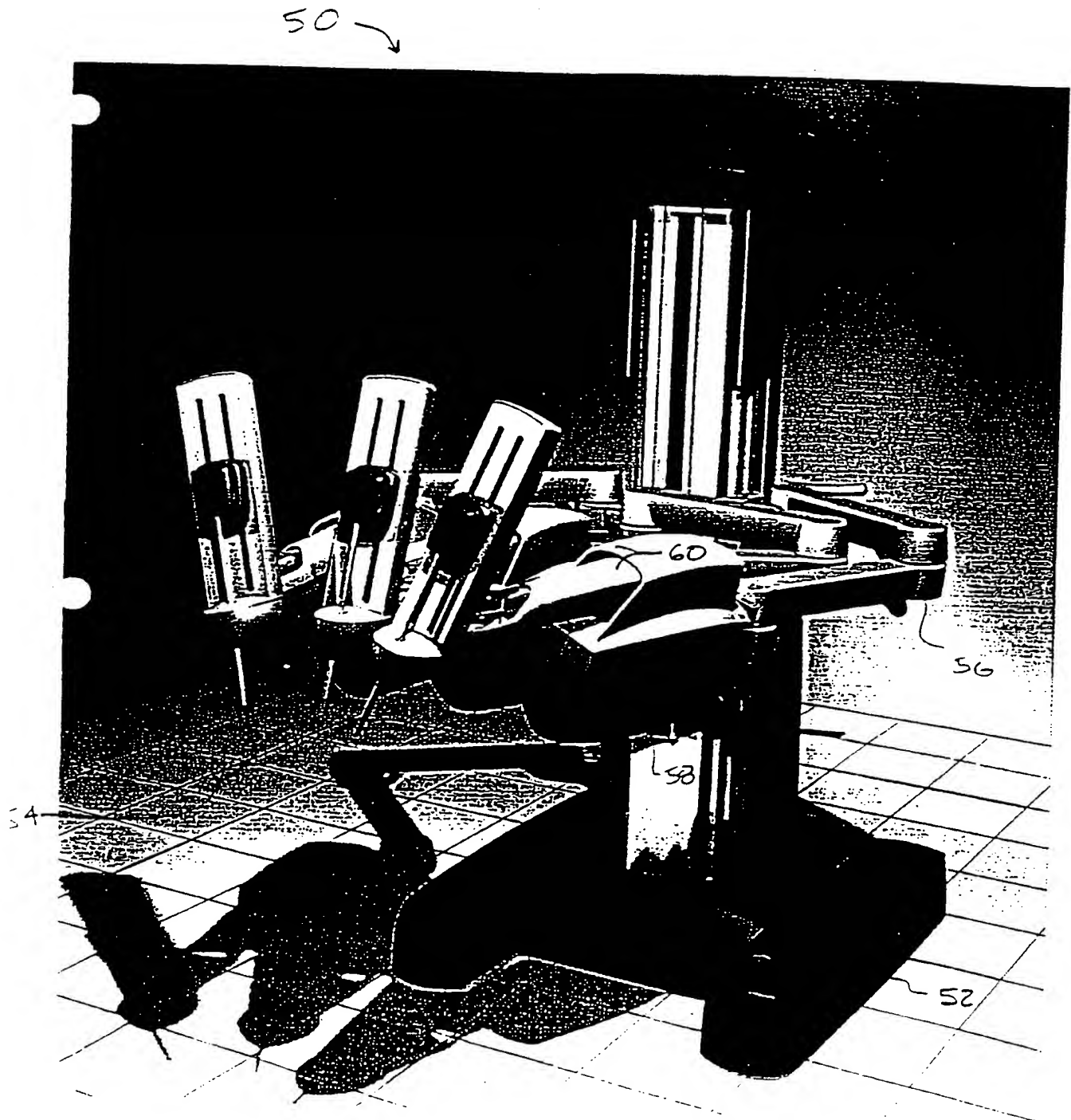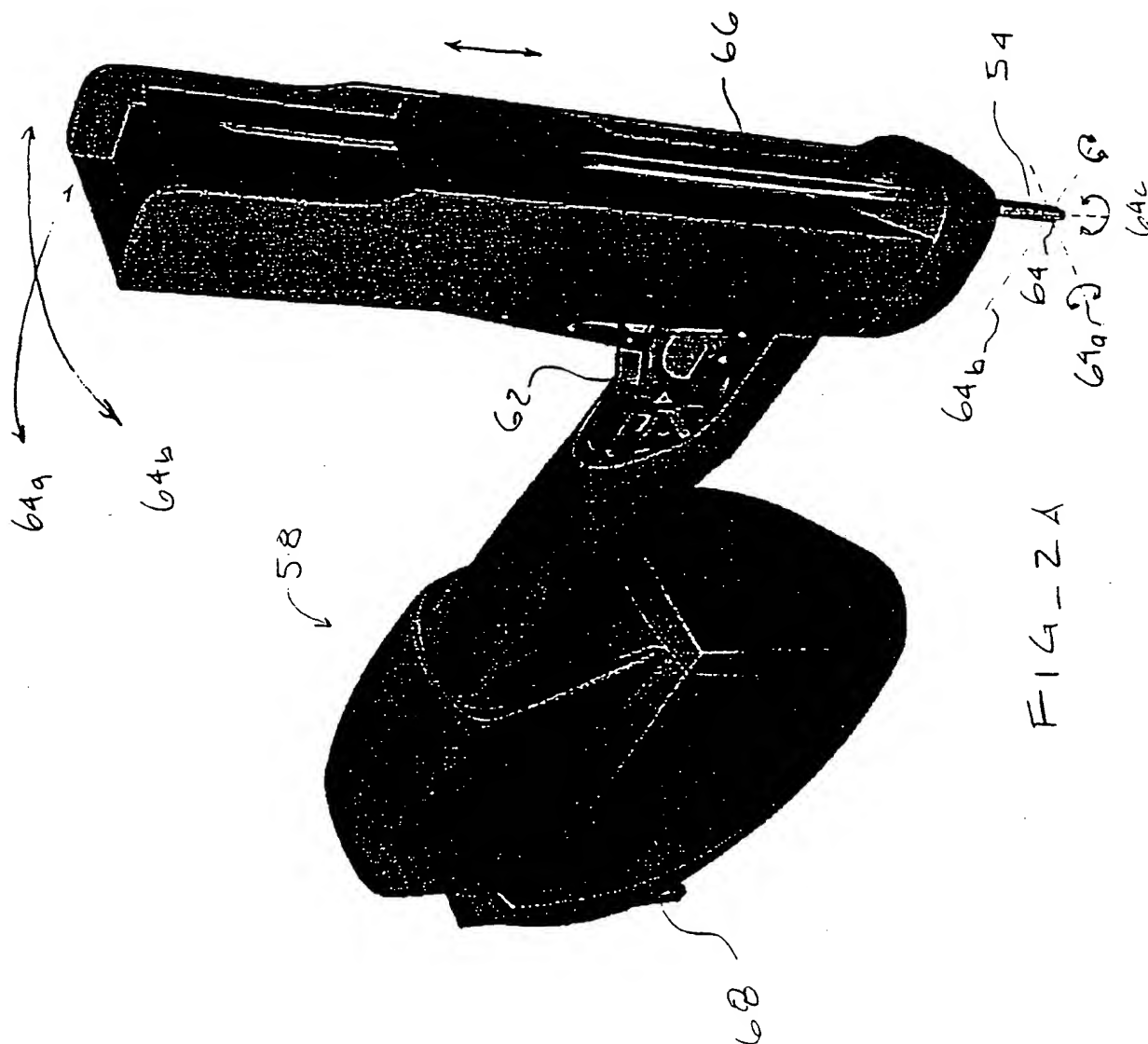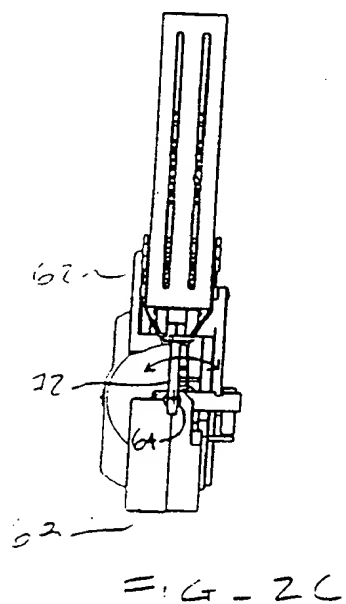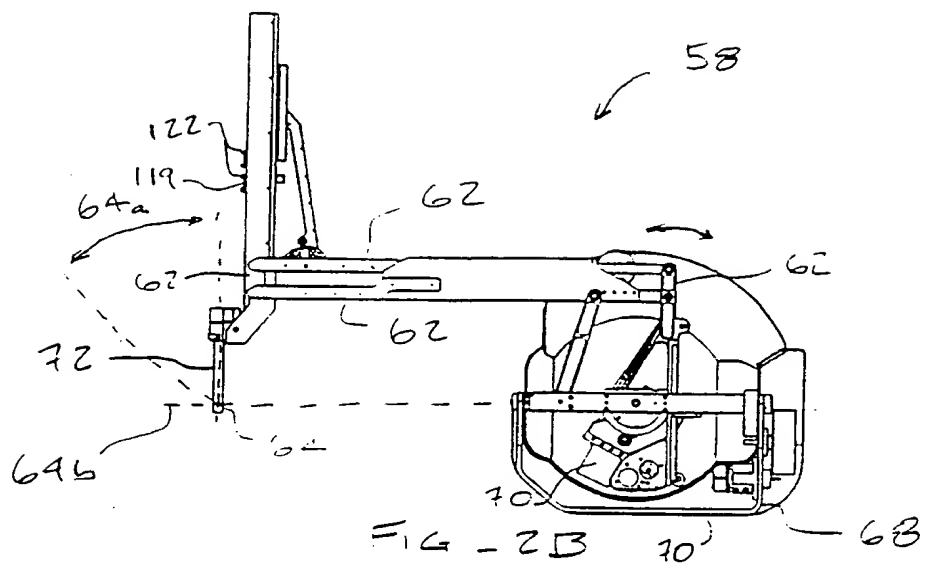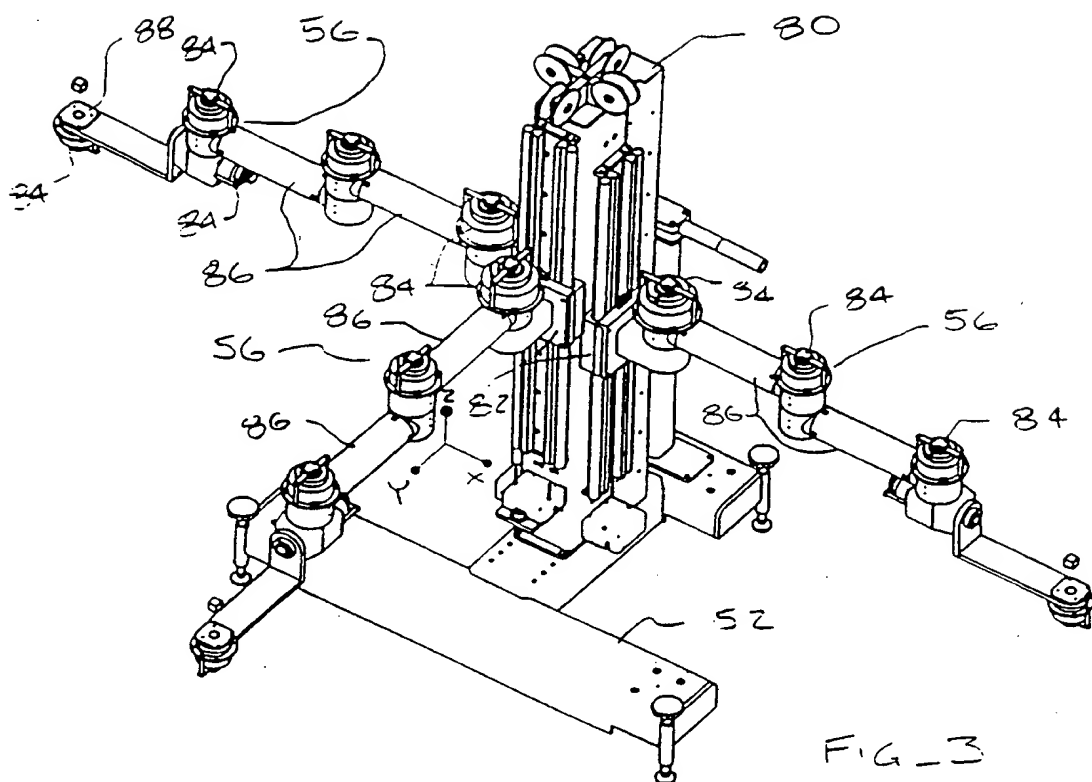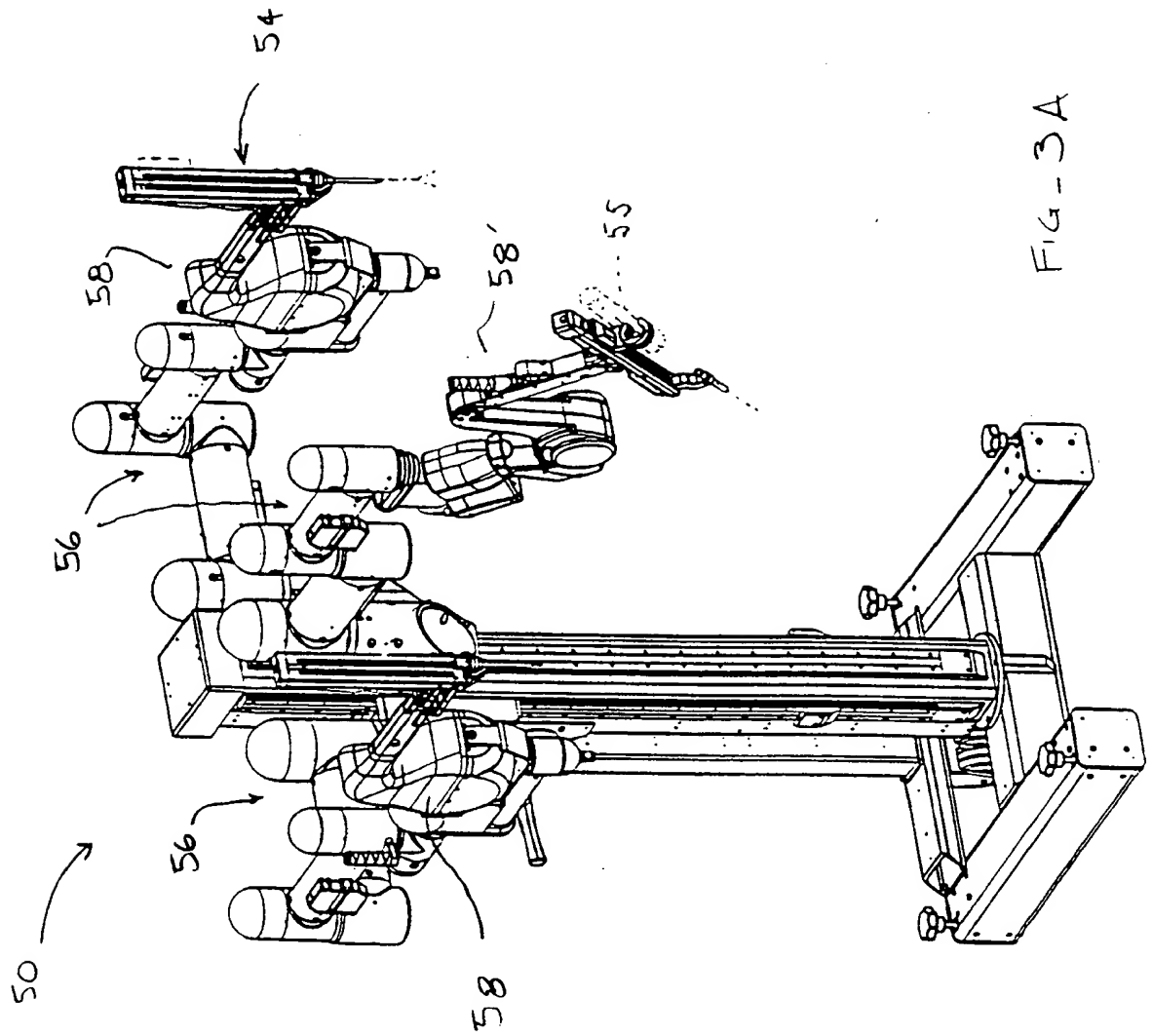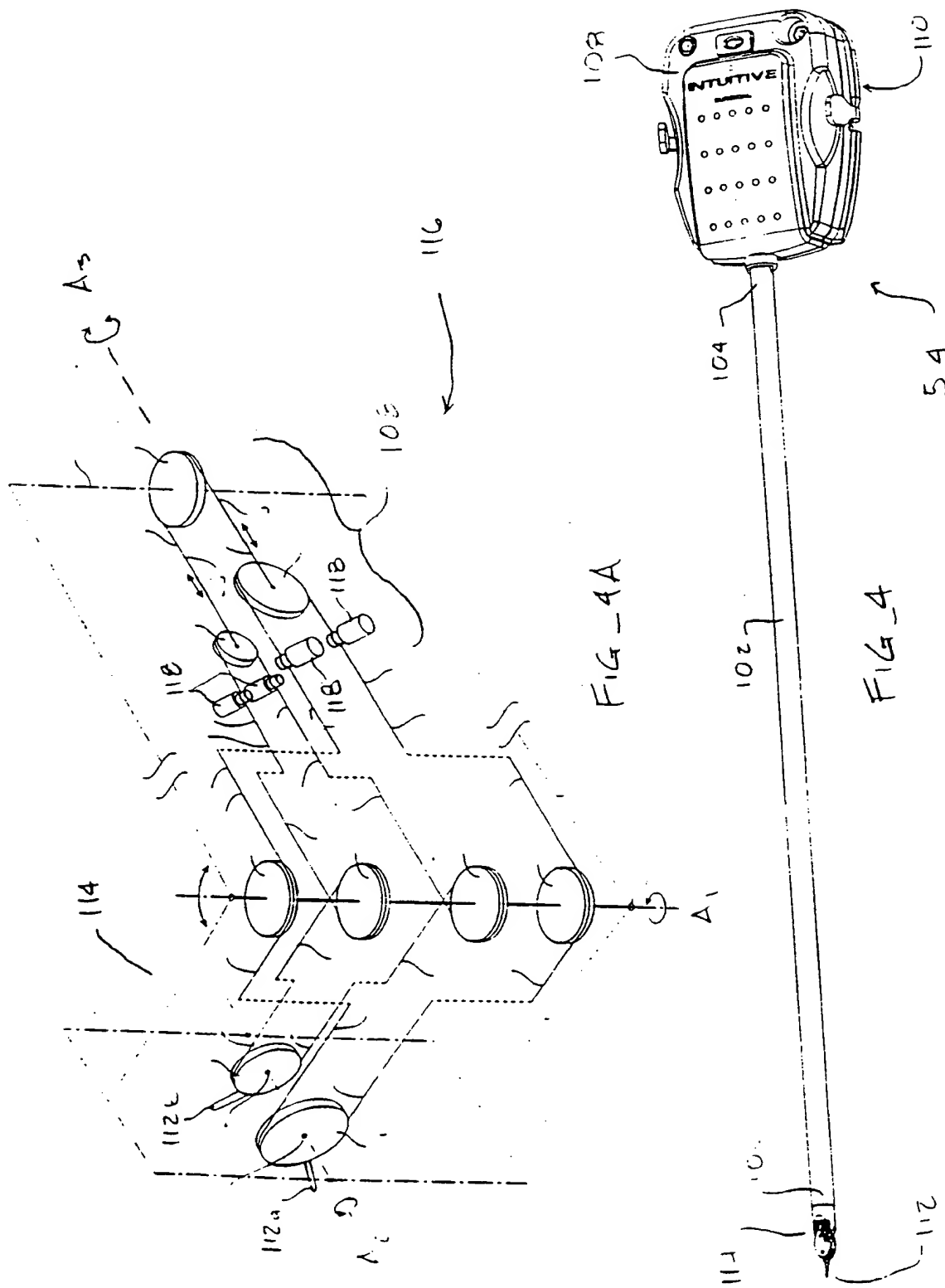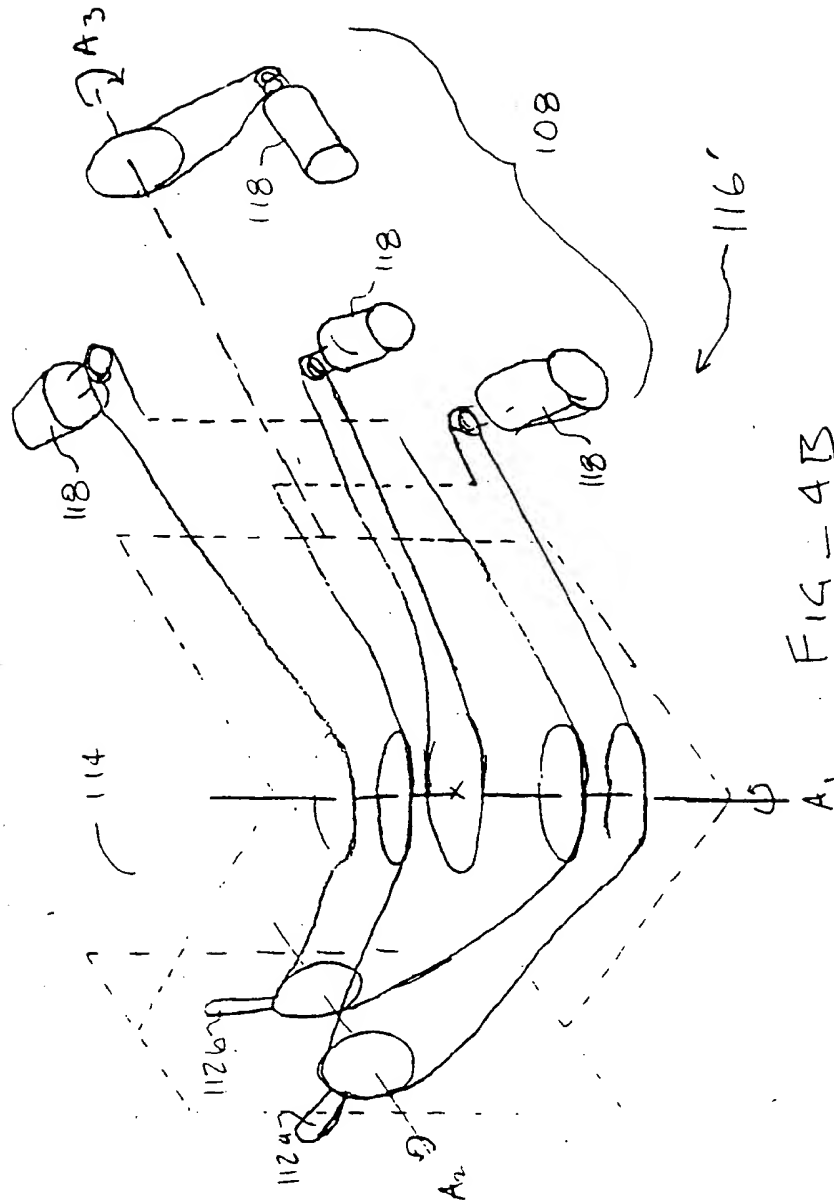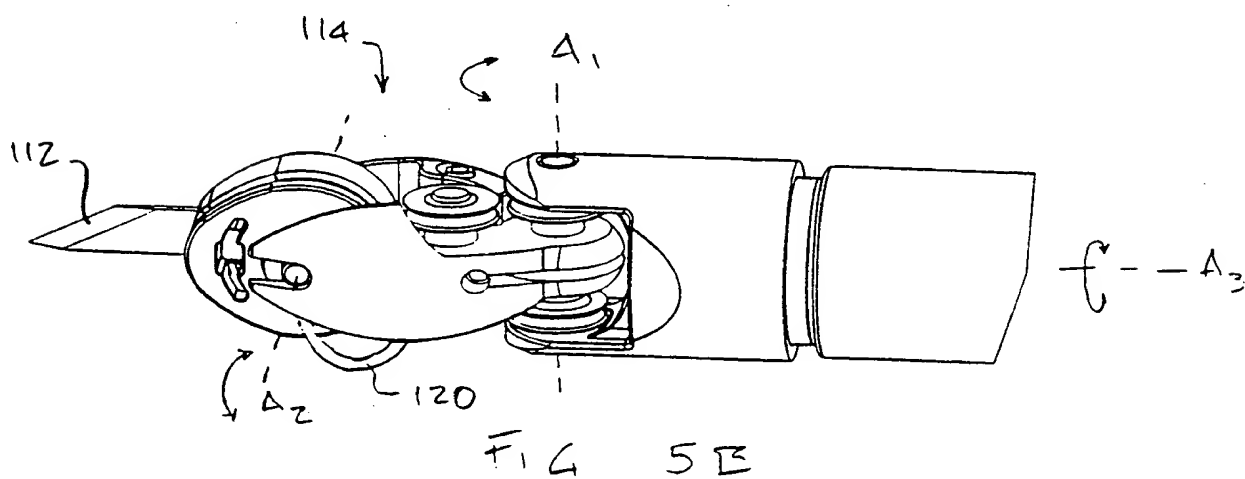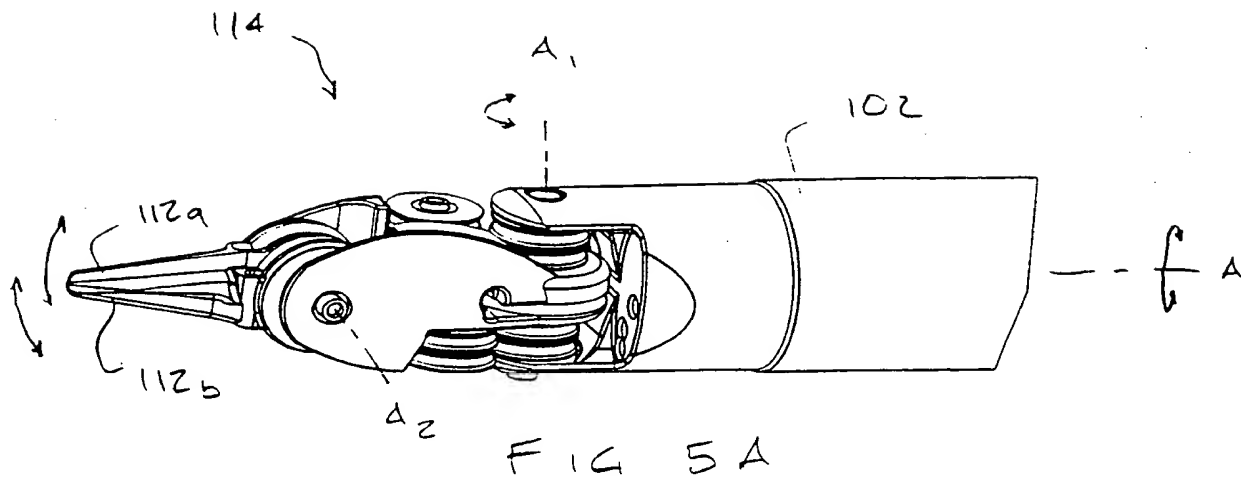
FIG-5C
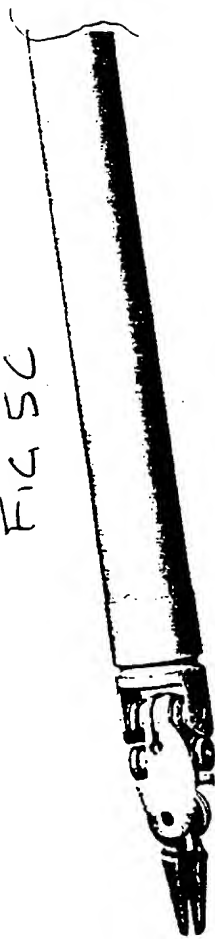
DeBakey Forceps

FIG-5D

Micro Forceps

FIG-5E
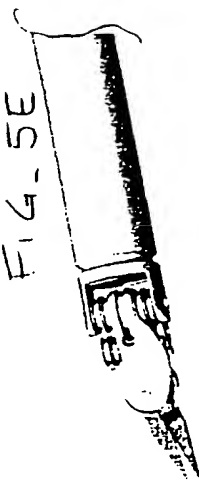
Potts Scissors

FIG-5F

Clip Applier

FIG-5H

Electrocautery
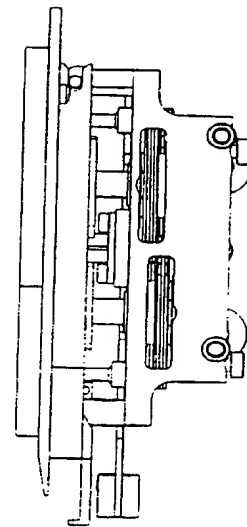
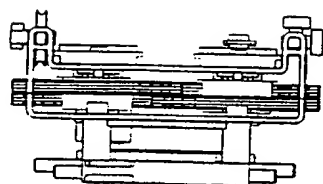FIG-5G
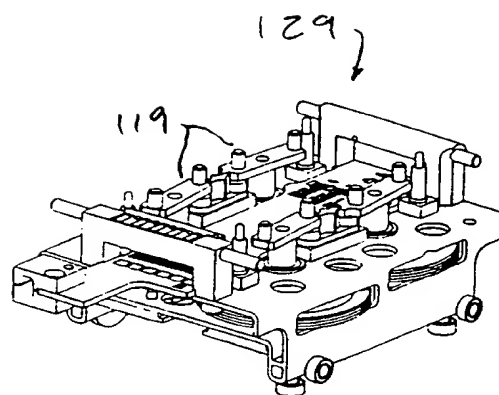
Scalpel

FIG_7B

FIG_7A

FIG_6

FIG_7E

FIG_7D

FIG_7C

FIG_7G

128

129
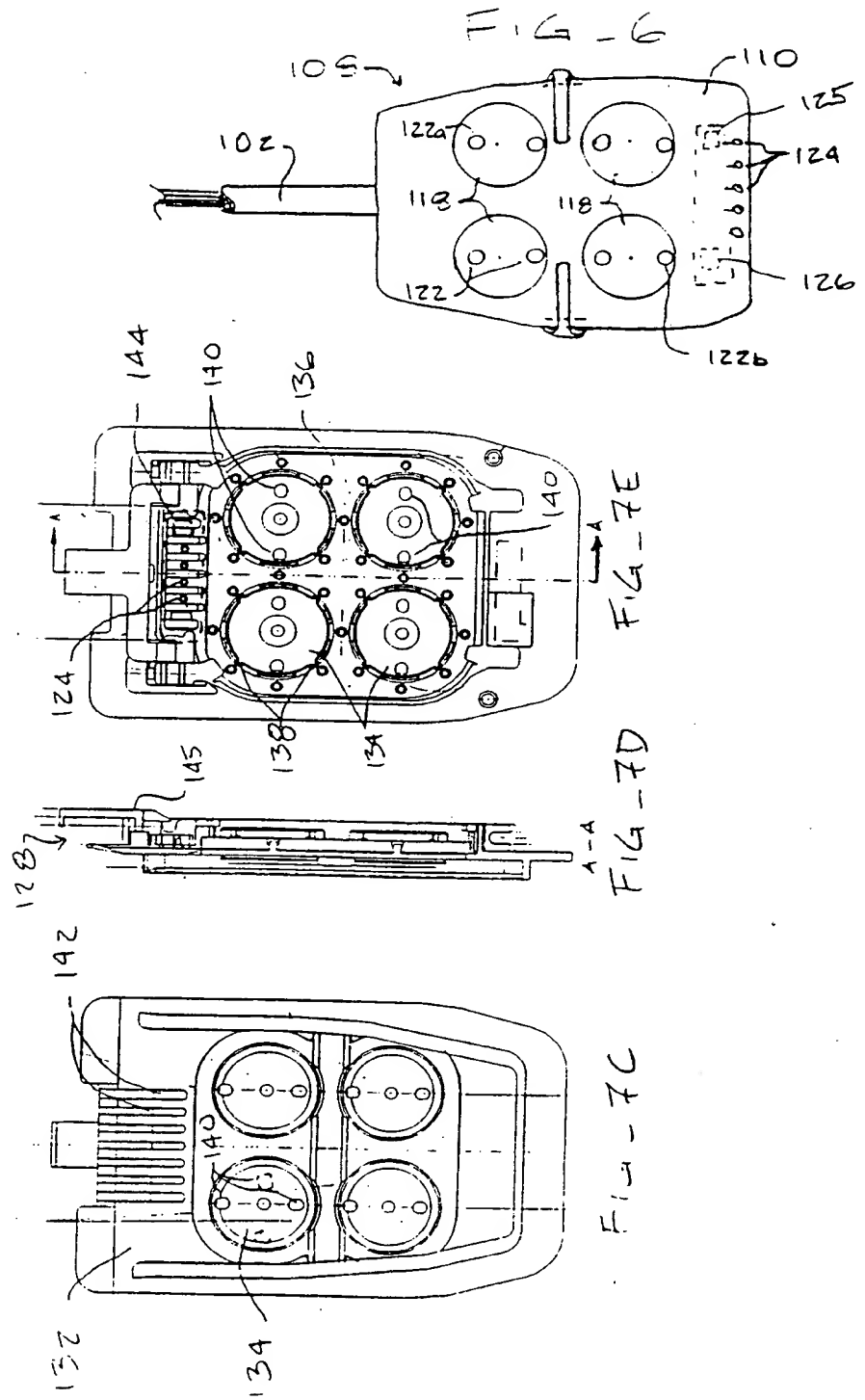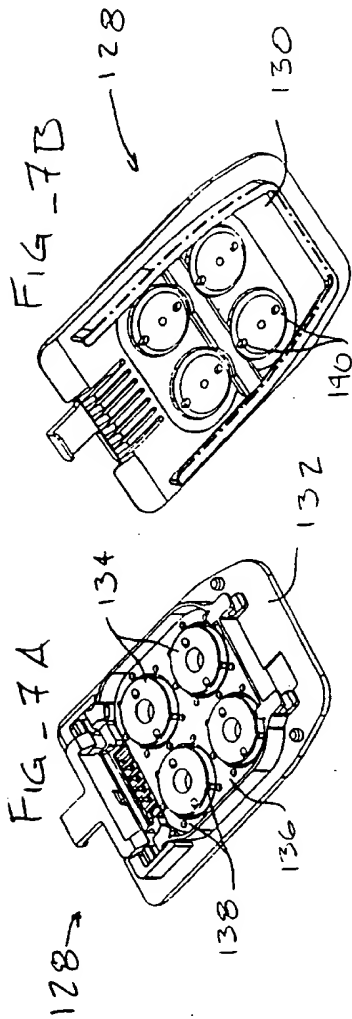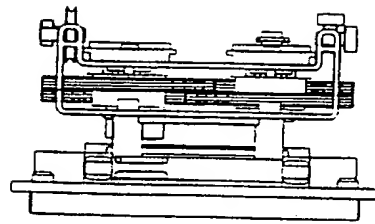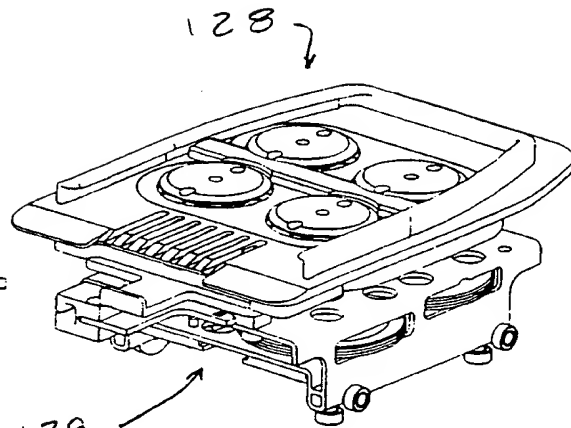
FIG_7F
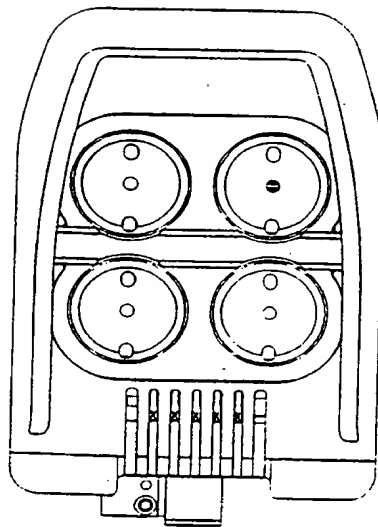
FIG_7H

FIG_7I

FIG _ 7K

FIG _ 7J

FIG _ 7M

FIG _ 7L

FIG - 6

150

154

FIG-8B

150

153
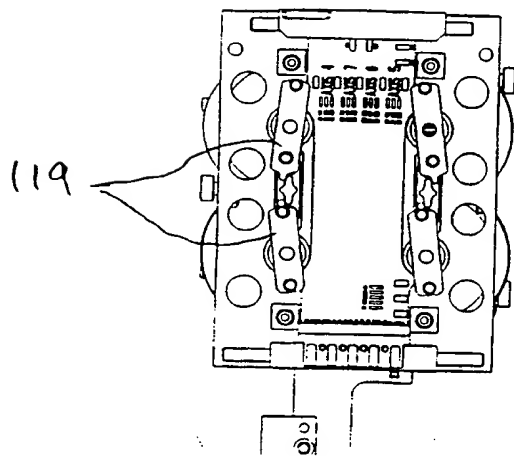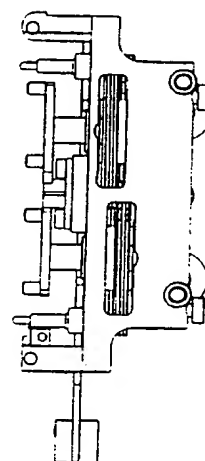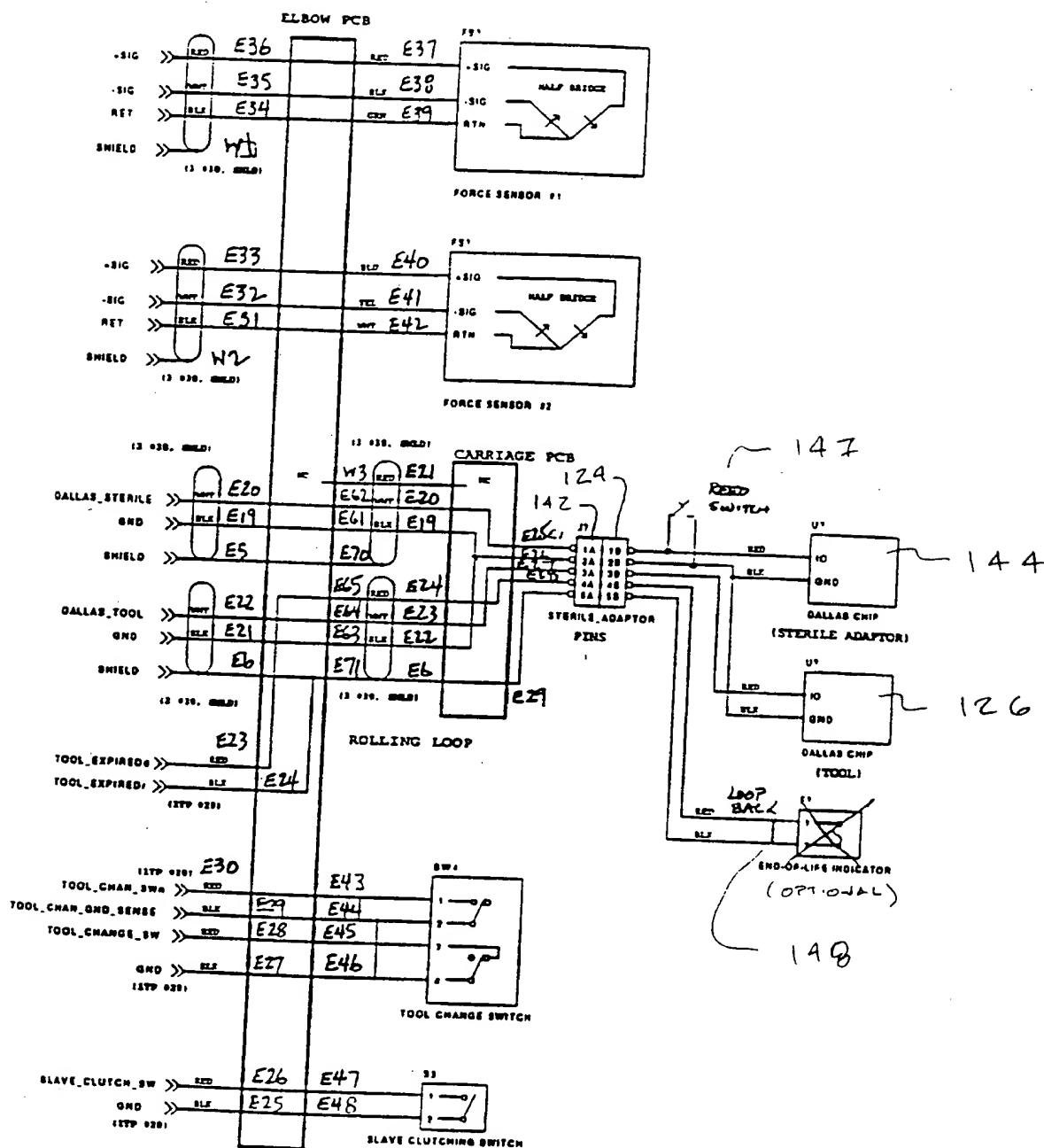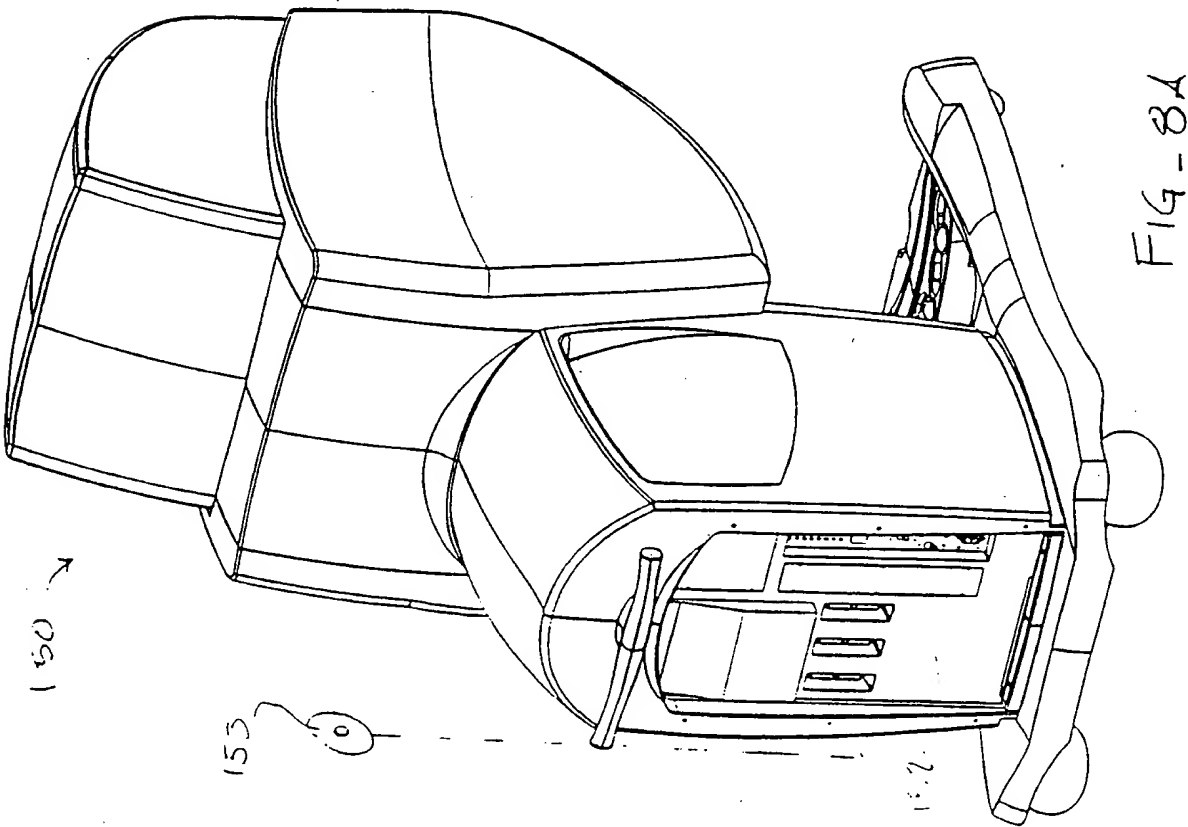
FIG-8A
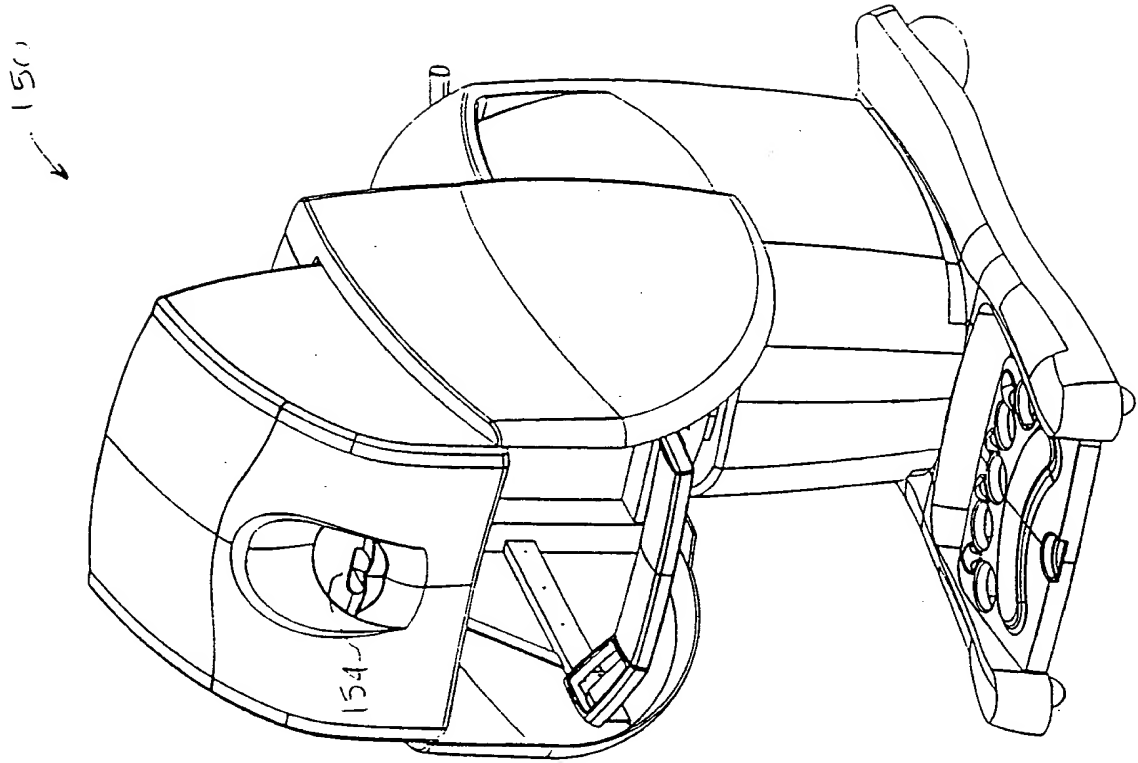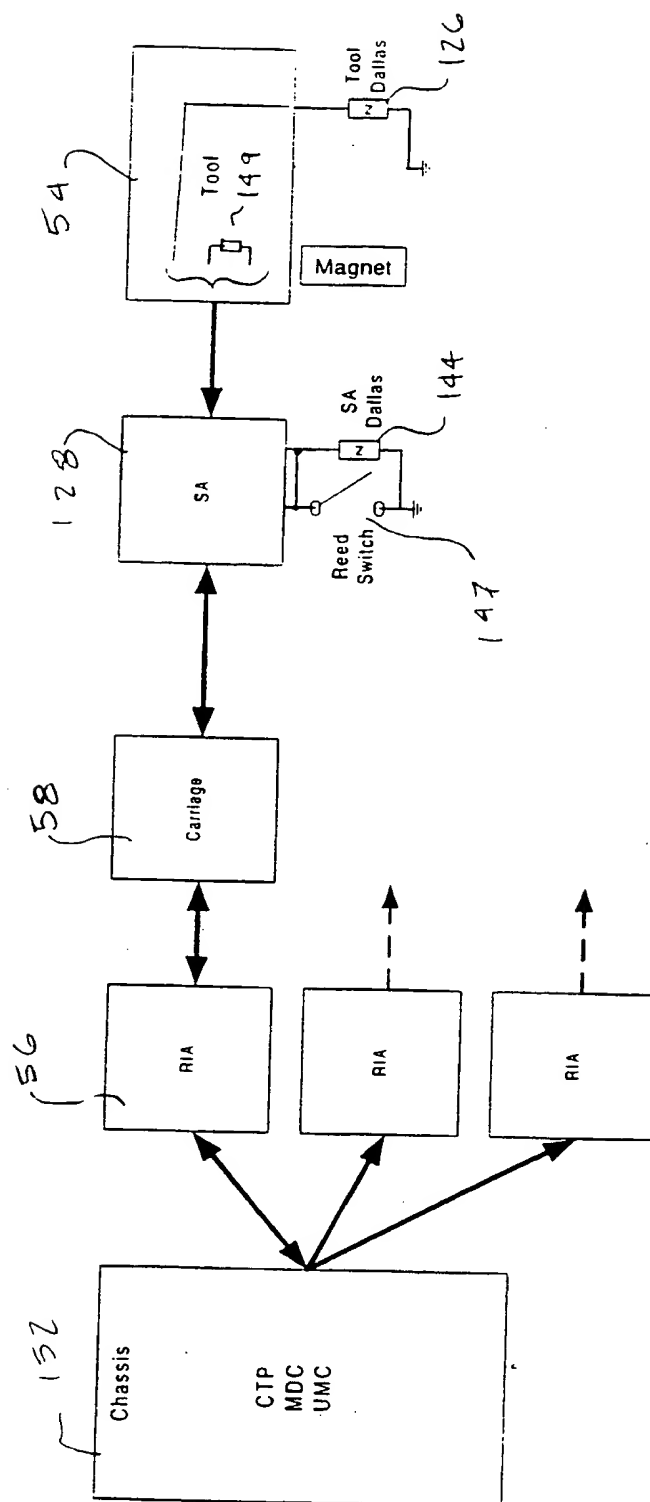
FIG _ 9
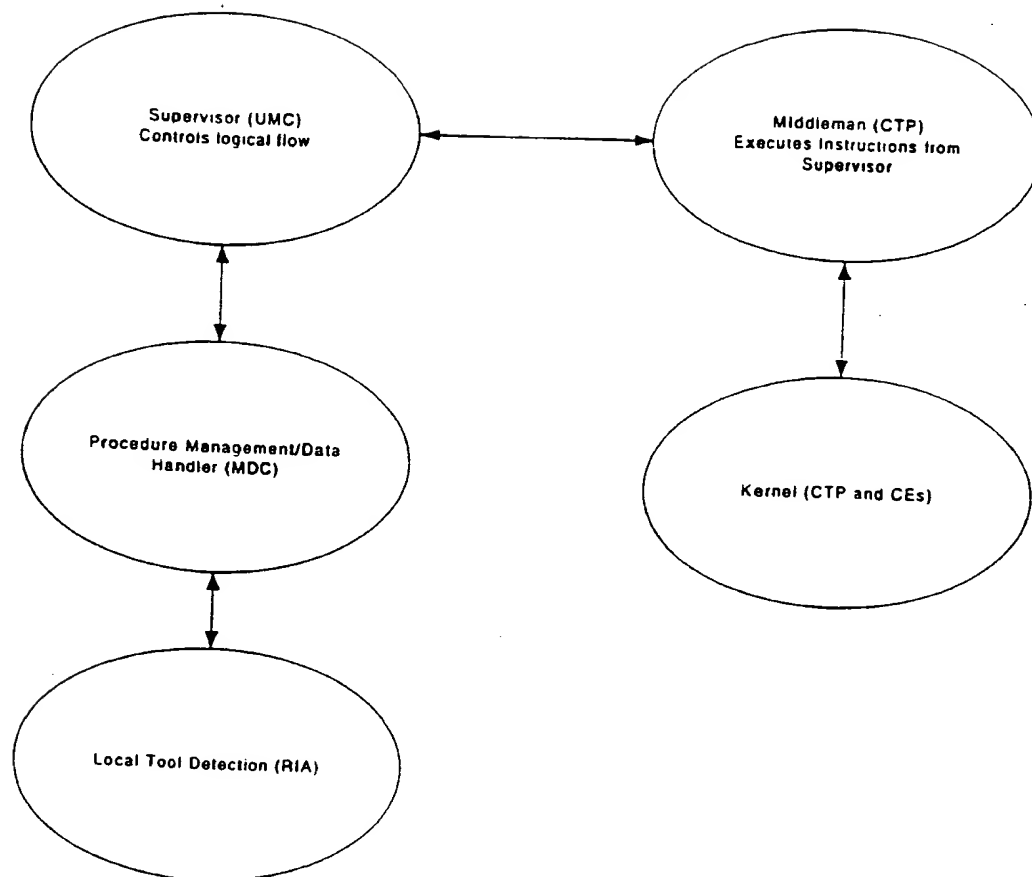
FiG _10

Sequence Flow

Detailed Sequence Blocks

Start

Check for SA

Check for Tool

Check for EOU

End

Start

Reed Switch Closed*

Reed Switch Open*

147

SA Present*

No SA Present*

144

End

*- Signifies message sent to indicate change in hardware state.

Start

No SA Present

SA Present

144

Tool Dallas Preset*

Tool Dallas Not Present*

126

End

Start

Tool Dallas Preset*

Tool Dallas Not Present*

148

End

FIG - 11

FIG _ 12

D = Dallas chip (1 = present, 0 = not present)
E = End of use indicator (0 = Open, 1 = Shorted)
R = Reed Switch (0 = open, 1 = shorted)

Events occur in DER order

e.g. 101 means Dallas chip present, End of use indicator
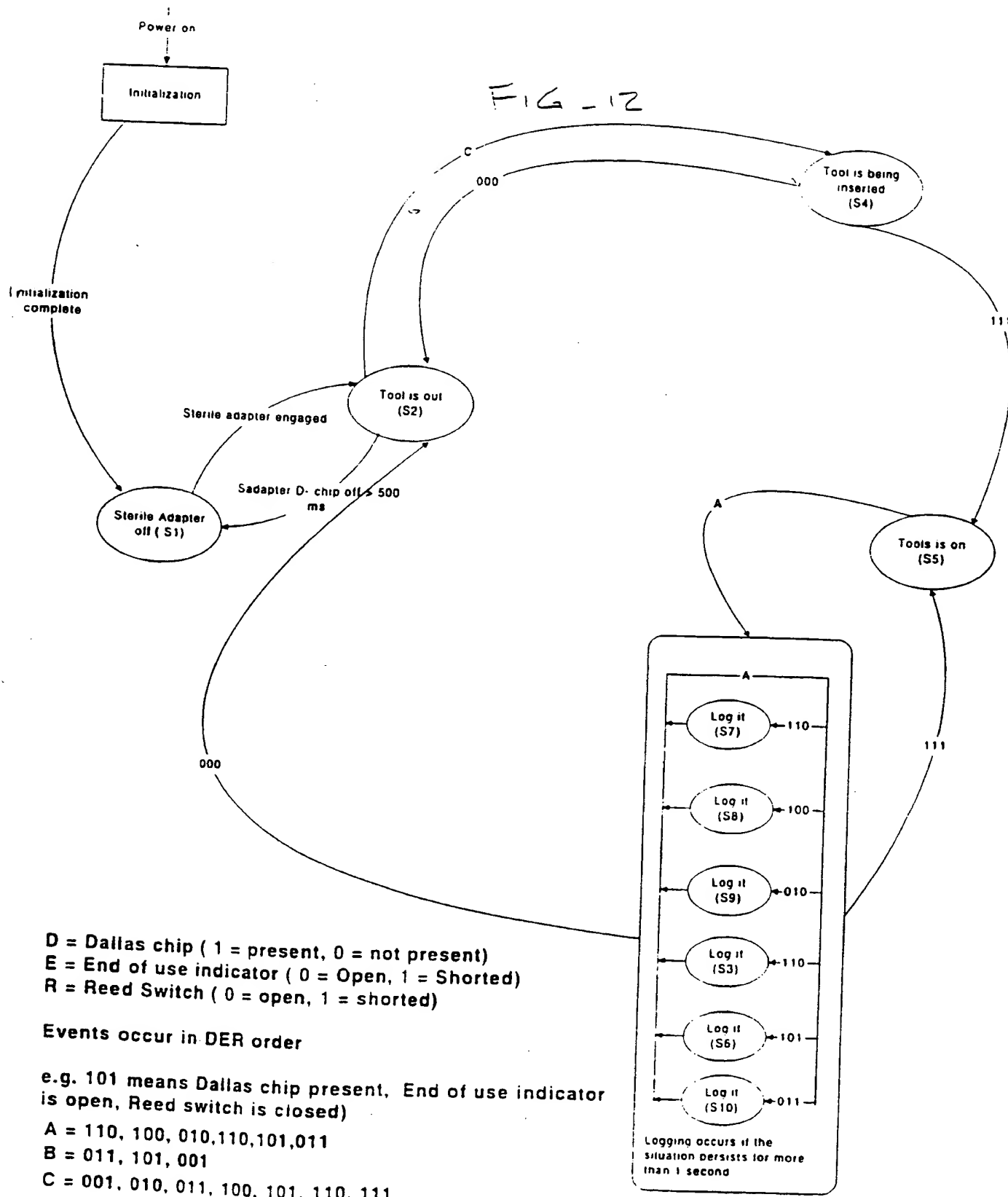is open, Reed switch is closed)
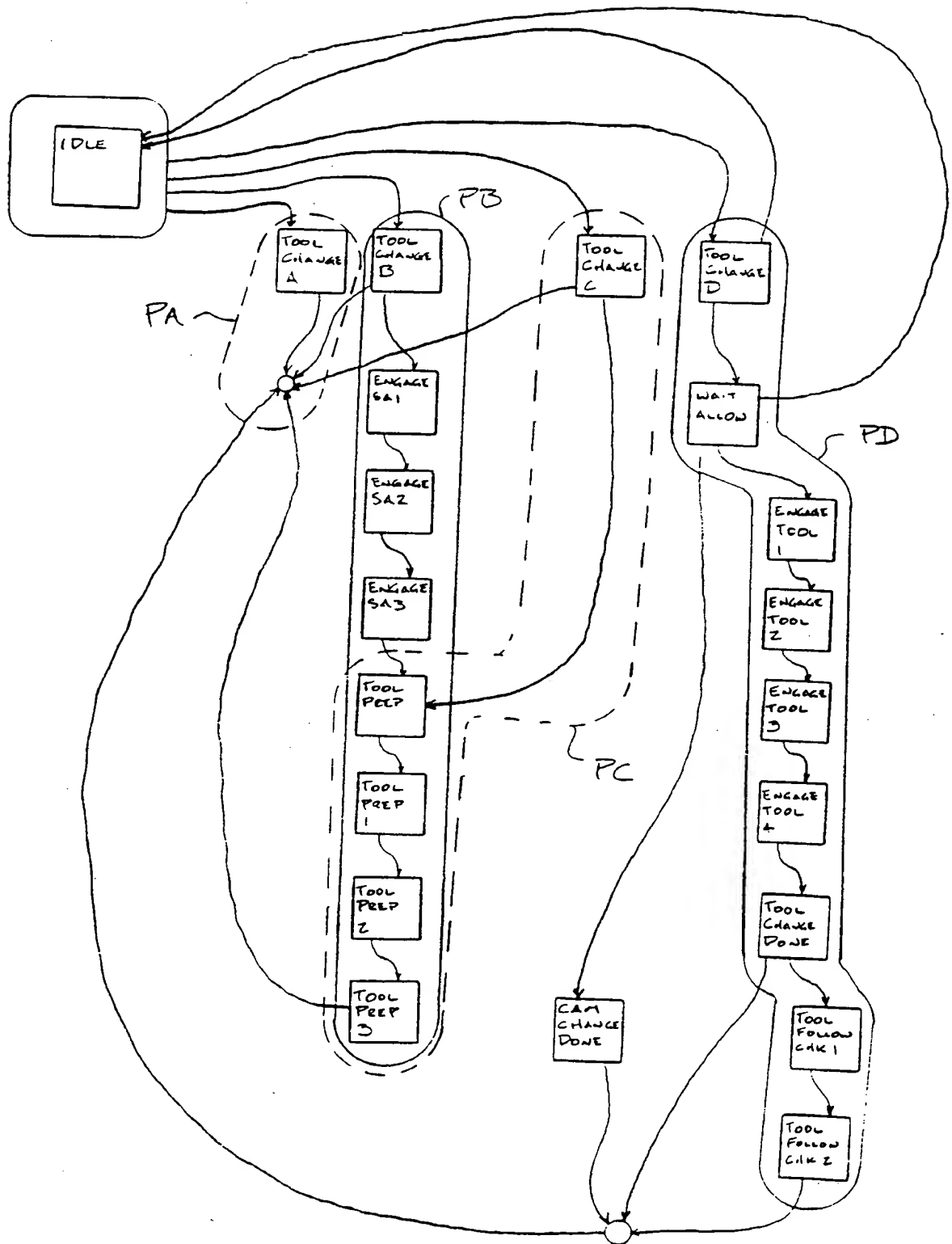
A = 110, 100, 010,110,101,011
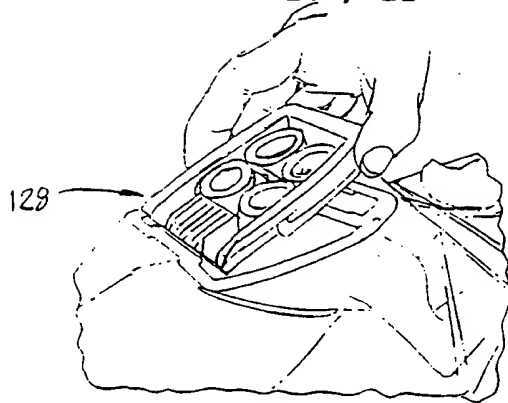B = 011, 101, 001
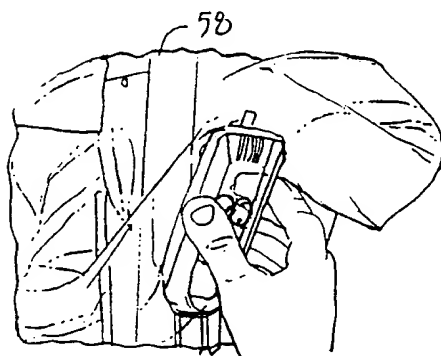C = 001, 010, 011, 100, 101, 110, 111

FIG - 13

FIG. 14A.

FIG. 14B.

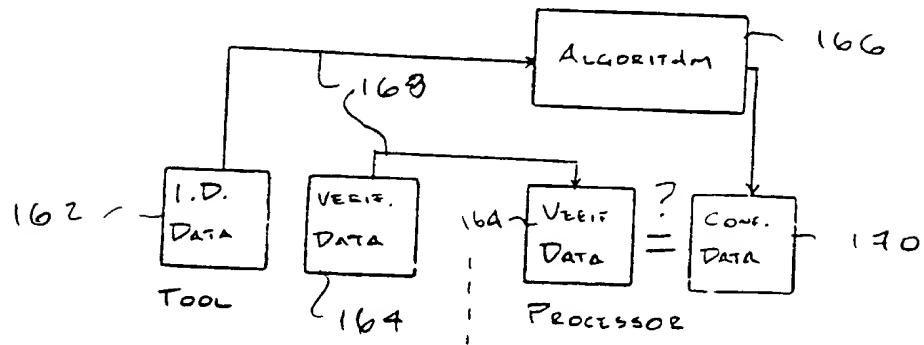FIG. 14C.
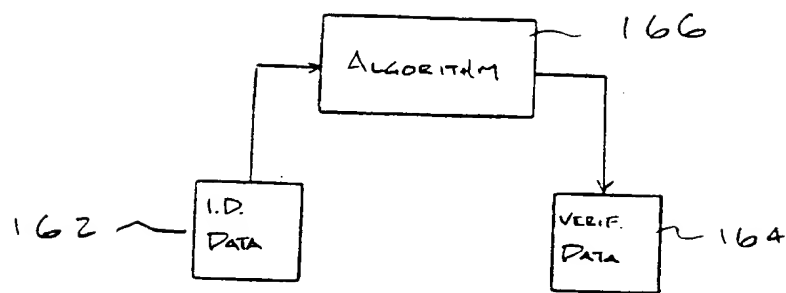
TOOL PRODUCTION
TOOL COMPATIBILITY VERIFICATION

FIG. 15

INTERNATIONAL SEARCH REPORT

A.   CLASSIFICATION OF SUBJECT MATTER
IPC(7)   :A61B 19/00
US CL   :606/130
According to International Patent Classification (IPC) or to both national classification and IPC

B.   FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. :   600/429; 606/130

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C.   DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,792,135 A (MADHANI et al.) 11 August 1998, Fig. 3.	1-3, 5-15, 27, 30
A	US 5,762,458 A (WANG et al.) 09 June 1998, Figs. 1 and 7.	1-3, 5-15, 27, 30
A	US 5,697,939 A (KUBOTA et al.) 16 December 1997, Figs. 2, 11, 12 and 16.	1-3, 5-15, 27, 30
A	US 5,649,956 A (JENSEN et al.) 22 July 1997, Figs. 1-2B and 4.	1-3, 5-15, 27, 30

☐ Further documents are listed in the continuation of Box C.   ☐ See patent family annex.

*	Special categories of cited documents:
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"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed

"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 APRIL 2000	0 9 MAY 2000

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D C 20231	MICHAEL PRIDDY
Facsimile No. (703) 305-3230	Telephone No. (703) 308-8620

Form PCT/ISA/210 (second sheet) (July 1998)*

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

EAST
Search Terms: (robotic OR automated) WITH surgical WITH system) AND (identification OR recogni$) WITH tool)
(5762458.pn. OR 5697939 OR 5649956 OR 5792135) AND magnet